ECLECTIC PHYSICAL GEOGRAPHY

HINMAN

Hinn

Come and see the works of God.

—Psalm lxvi: 5.

Old Faithful Geyser in Eruption, Yellowstone Park, Wyoming.

(Frontispiece.)

ECLECTIC

PHYSICAL GEOGRAPHY

BY

RUSSELL HINMAN

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PREFACE.

THE aim of this book is to indicate briefly what we know or surmise concerning the proximate causes of the more common and familiar phenomena observed at the earth's surface. Even thus restricted, the field of inquiry encroaches to a greater or less extent upon the domains of all the branches of science.

Since the study of Physical Geography precedes that of the sciences in most of our schools, it has been thought advisable to present, in the form of an introductory chapter, a condensed statement of the more important and fundamental scientific conceptions regarding the properties and phenomena of matter and energy, such as inertia, gravitation, cohesion, affinity, and heat, light, magnetism, and electricity. This chapter may be studied or simply read, at the discretion of the teacher.

The order of treatment of the different parts of the subject proper is that which seems most natural and rational. After describing the relations of the *planet* to the solar system, its movements and their effects, the *atmosphere* is at once considered, not only because it forms the true outer layer and envelope of the earth, but because its action is the proximate cause both of all details in the relief of the land, and of the more conspicuous phenomena of the sea. The *sea* is next discussed, since it forms an intermediate layer between the atmosphere and three fourths of the earth's solid surface, and since the peculiarities in the relative position, composition, and relief of the land masses can be appreciated only after some acquaintance with the depth and character of the bottom in different regions of the sea. In the treatment of the *land*, which then follows, the methods by which its surface contour is constantly modified by atmospheric agencies are explained at greater length than is usual in current text-books, while the influence of subterranean agencies in changing the elevation of the land is carefully considered. *Climate*, being the average local condition of the atmosphere, as determined largely by the peculiarities of the surface upon

which it rests, is appropriately treated after that surface has been discussed, and fittingly precedes the concluding chapters on *life.* These chapters embrace a brief description of the more conspicuous phenomena of the organic world. The close dependence of plants and animals upon their inorganic surroundings and upon each other is pointed out, as well as the remarkable series of facts which is held by many scientists to indicate that all organisms are of kin.

In a study of this kind it is well to remember that, with all the scientific knowledge of the nineteenth century, we are still profoundly ignorant of the ultimate causes of things, while our ideas of proximate causes are constantly being revised and changed as our acquaintance with nature increases. The broadest scientific generalizations of one generation are apt to be swept away or greatly modified by the next, and our descendants will doubtless regard the science of to-day much as we regard that of the ancients. Yet, notwithstanding its crudities and absurdities, ancient alchemy gradually developed into modern chemistry, which has been of inestimable value to man; and in the same way, the more perfect knowledge of the future is to be acquired only through familiarity with the imperfect theories of to-day.

The maps in the book have been carefully prepared in various projections, each adapted to portray most accurately the special feature under consideration, and, with the cuts and diagrams, are inserted to *illustrate,* and not simply to beautify the text.

The acknowledgments of the author are due to the United States Geological Survey, Coast and Geodetic Survey, Signal Service, and Hydrographic Bureau for maps and information courteously supplied. He also takes this opportunity to acknowledge gratefully the valuable assistance rendered in revising the proof-sheets of the introductory chapter, by Prof. T. H. Norton, of the University of Cincinnati; of the chapters on the atmosphere and climate, by Prof. Cleveland Abbe, of the U. S. Signal Service, and Prof. W. M. Davis, of Harvard College; and of the chapters on the land by Capt. C. E. Dutton of the U. S. Geological Survey.

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INTRODUCTION.

SOME GENERAL LAWS OF NATURE.

Show me thy ways, O Lord, teach me thy paths.—PSALM XXV: 4.

Laws of Nature.—Nothing in nature is permanent; every thing is constantly changing. Day changes into night, fair weather into foul, plants and animals die and decay, and even the solid rocks gradually wear away into soil or sand. These changes do not occur by chance, but each is the result of some definite cause, and, under similar circumstances, precisely the same effects are produced by the same causes. The invariable relations between causes and resulting effects constitute the *laws of nature*.

Physical Geography seeks to trace the operation of the laws of nature upon the earth: upon the air, the water, and the land; upon plants, animals, and even upon man.

Matter is the general name given to the material of which any body, such as rock, water, or air, is composed.

Kinds of Matter.—The number of substances in the world is almost infinite; yet most of them are compound substances, and can be broken up into a comparatively few distinct kinds of matter, from which no other kind can be obtained. These are, therefore, called simple substances, or *elements*.

Constitution of Matter.—All matter is conceived to be built up of minute particles, called *molecules*. A molecule is the smallest fragment of any substance that can exist by itself. A molecule of a compound substance breaks into the simple substances of which the compound is composed; and a molecule of a simple substance breaks into still smaller fragments, called *atoms*, which are too small to exist by themselves, but large enough to unite with other atoms of the same or different kinds of matter to form a simple or a compound molecule.

Molecules are too small to be visible even with the aid of the most powerful microscope. Some idea of their extreme smallness may be gathered from Sir William Thomson's estimate. He says that if a drop of water were magnified to the size of the earth, its molecules, so magnified, would be about as large as base-balls.

Common Properties of Matter.—All matter of whatever kind is indestructible, impenetrable, and possesses inertia. By virtue of the first quality, it is absolutely impossible to destroy a single atom or molecule in nature. A substance may disappear, but new substances are always formed of its constituent atoms. By virtue of the second quality, two particles can not occupy the same space at the same time. A nail driven into a board does not penetrate the molecules of the wood: it simply forces them aside.

Fig. 1.

Inertia.—All matter resists being set in motion, and, when moving, resists any change in the rate or direction of its motion. Hence, no body can either start into motion or stop when moving unless something outside of itself pulls or pushes it powerfully enough to overcome this resistance. This resistance of matter is called its *inertia*.

The inertia of bodies increases with the amount of matter they contain. Thus, if two balls of iron, a large one and a small one, be suspended by long cords, the large one will require a more powerful pull or push to start it to swinging or to stop it than the small one. If a ball of cork, of the same size as one of the iron balls be suspended, it will require a less powerful pull or push to start or stop it than the iron ball. The iron ball, therefore, though of the same size, contains a greater quantity, or *mass*, of matter, and possesses greater inertia than the cork ball.

Forces of Nature.—A pull or a push of any kind or strength always tends to overcome inertia, and is called a *force*. There are three great natural forces by whose varying action the few elemental substances are gathered and held together into the infinite variety of groups or bodies of nature. These forces are *Gravitation*, *Cohesion*, and *Chemical Affinity*.

Gravitation is a force which is constantly acting upon all matter in nature. By virtue of this force, each molecule of matter tends to attract, or pull toward itself, every other molecule, however distant. Since each molecule exercises this attraction upon others, a body composed of a great number of molecules, or of a large *mass* of matter, exercises a stronger attraction than bodies of fewer molecules or less mass. The mass of the whole earth is so enormous that its attraction quite overpowers that of detached bodies near its surface; these, therefore, if unsupported, yield to the attraction of the greater mass, and move or fall toward the earth. If the body is supported, the attraction of the earth causes it to push or press against its support. This pressure is called the *weight* of the body.

Some bodies do not fall, but ascend—as smoke or a balloon in the air, or a cork or oil under water. This is not because the earth does not attract them, but because an equal bulk of the air or water immediately above the body contains a greater mass of matter, and is, therefore, more strongly attracted by the earth than the body

itself. The body and the greater mass of air or water above it consequently exchange places—the greater mass sinking, and forcing the smaller mass to rise. When two bodies are weighed in the same place and under similar conditions, the heavier always contains the greater mass of matter even if it is much the smaller body. Thus, 1 cubic foot of rock, 2 cubic feet of water, 8 cubic feet of cork, and 1.600 cubic feet of air have about the same weights and the same inertia, and, consequently, are equal to each other in mass, though the bulk of the cork is four times that of the water, and eight times that of the rock. If the bulks were equal, the rock would weigh twice as much as the water, the cork one fourth as much, and the air but one eight hundredth as much. The *specific gravity* of a substance is such a comparison of its weight with that of an equal bulk of some other substance, usually water, taken as a standard. Thus, the weight of water being called *one*, the specific gravity of rock is two, of cork one fourth, of air one eight hundredth.

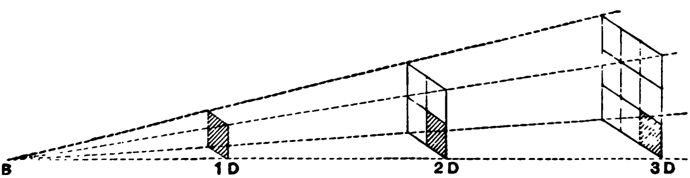


Fig. 2.

Distance.—Although the attraction of gravitation acts between bodies, however far apart they may be, the power or intensity of this force decreases very rapidly as the distance between the bodies increases. Thus, gravity acting from B is distributed over four times the space at $2D$, and nine times the space at $3D$ that it is at $1D$; hence, if the distance between two bodies is doubled or trebled, the mutual attraction of gravitation which they exert on each other is decreased to one fourth and one ninth respectively; in other words, ***the intensity of gravitation varies inversely as the square of the distance between the bodies.*** This law applies to sound and to radiant heat and light as well as to gravitation.

The effects of Gravitation are almost infinite in number, and many of them are familiar to every one. In general, gravitation gives *weight* to all substances in nature—even to such light and invisible substances as air—and therefore this force is one of the causes of all phenomena in which the weight of bodies plays a part. The rising of vapor through the heavier air, and the falling of rain through the lighter air; the moving of heavy air, as wind, to a region where the air is lighter; and the downward flow of streams over the sloping surface of the land,—all these are caused by the attraction of the enormous mass of the earth upon the relatively insignificant masses of matter near its surface.

The effect of the earth's attraction, however, is not confined to the neighborhood of its surface. The nearest heavenly body, the moon, is much smaller than the earth; it contains but one eightieth as much matter. Though 240,000 miles distant, the attraction of the larger earth pulls this body constantly from the straight course which its inertia influences it to follow, and causes the moon's path or orbit to become nearly circular around the earth. The moon's attraction upon the larger earth is imperceptible on the solid land, but it heaps up the waters of the sea to form the tides. But the attraction of gravitation extends to all distances. The sun is a body whose mass is 300,000 times as great as that of the earth and moon together. The attraction of this vast mass, exerted through a distance of 92,000,000 miles, overcomes the earth's inertia, and causes the earth and the other planets of the solar system to move around the sun in nearly circular orbits—just as the earth influences the movement of the moon. The effect of the sun's attraction upon the earth is seen in the regular recurrence of the seasons, and the regular variation in the length of the day and night. Each fixed star is, probably, like our sun, the center of a system of planets. Each of these systems, as a whole, has, like the solar system, a motion of its own through limitless space, which is modified and regulated according to the mass and distance of the various systems by this universal force of gravitation.

Cohesion, like gravitation, is an attractive force which may act on every molecule in nature. But it is unlike gravi-

tation in three important particulars: (1) it acts only between individual molecules, and not between masses; (2) it acts only between molecules of the same kind of matter; and (3) it acts only when the molecules are exceedingly close together,—so close that they seem to be in absolute contact.

It is the force of gravity acting between the mass of the earth and the mass of a stone which causes the stone to fall to the earth; but it is the force of cohesion acting between the millions of individual stone molecules which causes them to stick together and form the solid mass of stone. A man lifting a bucket from a well, or carrying a heavy basket, is thus overcoming the force of gravity; while a woodman chopping down a tree, or a machinist filing a piece of iron, is struggling against the force of cohesion.

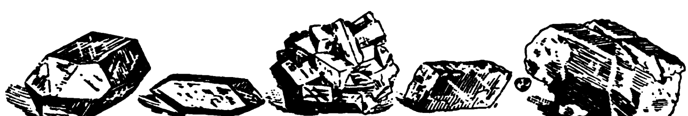
State of Aggregation.—It is believed that between the molecules of all bodies two antagonistic forces are constantly struggling for mastery: the attractive force of cohesion, and a repulsive force, which results in what we call "heat." When the attractive force is the stronger, the molecules cohere (stick together) and form a *solid;* when the two forces are about equal, the molecules move about, over, and beside each other, and form a *liquid;* when the repulsive force is the stronger, the molecules fly farther apart, and form a *gas.*

It thus depends simply upon the relative intensities of cohesion and heat between the molecules of any substance, whether that substance takes the form of a solid, a liquid, or a gas. Ice, water, and steam, for example, may be produced from the same molecules by simply making them colder or hotter. It is believed that there is no substance which may not exist in any one of the three states of aggregation,—a solid, a liquid, or a gas.

Crystallization is a peculiar effect of cohesion frequently seen in rock, cast iron, snow, and very many other solids. When a substance passes slowly and quietly from a liquid to a solid state, the molecules generally arrange themselves in a peculiar manner, assuming certain

definite geometrical shapes. These shapes vary in different substances, but remain constant in substances of the same kind.

If water, for instance, be examined when solidifying, or *freezing*, delicate needles of ice will be observed shooting out over the surface and forming six-pointed stars or little six-sided figures. These are *ice crystals*, and, if observed in freezing water in any part of the world, the ice-needles are always found to form angles of just 60° with each other. If a solution of table salt be allowed to solidify, the salt takes the form of little cubes with exquisitely smooth sides, and clean, square angles. These are salt crystals. In general, every substance forms crystals, which are always the same in the same



1 2 3 4 5

Fig. 3.—1. *Quartz.* 2. *Gypsum.* 3. *Salt.* 4. *Calcspar.* 5. *Feldspar.*

substance, but different in shape from the crystals of other substances. Crystallization is explained by supposing that the cohesive force of molecules is not exerted equally on all sides, but is stronger in certain definite directions, and that there are differences in this respect between the molecules of different kinds of matter.

The power of Cohesion is, of course, greatest in solids, but it varies in different substances. The cohesive attraction is so strong that it requires a pull of

100,000 to 170,000 lbs.	to	break	a steel	bar	1	inch	square.
50,000 to 100,000 lbs.	"	"	" iron	"	"	"	"
4,000 to 20,000 lbs.	"	"	" wooden	"	"	"	"
500 to 1,000 lbs.	"	"	" stone	"	"	"	"

The change in the arrangement of water molecules, under the force of cohesion causes the bursting of water-pipes, when the water in them crystallizes, or *freezes*.

The molecules of water and of some other substances occupy a greater space when the absence of heat allows cohesion to arrange

them in the form of *crystals*, than when, heat being present, it overcomes cohesion and arranges the molecules so that they slide over each other in the form of a liquid. Hence, the contents of a water-pipe expands as it changes from a liquid to a crystallized form. It expands with a force which, at the ordinary temperature of freezing water, produces an outward pressure of more than 2,000 pounds on each square inch of the interior of the pipe, and this pressure increases rapidly as the temperature falls. Few pipes can withstand this pressure, and, consequently, they burst. If the pipe is strong enough, however, to prevent the expansion, the water can not freeze, but remains liquid.

Adhesion is a force similar to cohesion, except that while cohesion acts only between molecules of the same kind of matter, adhesion acts only between molecules of different kinds.

No body can become wet when plunged into water, if the adhesion between the molecules of the water and the body is weaker than the cohesion between the molecules of the water. Grease is such a substance, and, therefore, does not become wet.

Capillary Attraction is an instance of adhesion, and is so named from the Latin word *capillus*, a hair. When one end of a fine, hair-like tube is plunged into any liquid that will adhere to the material of which the tube is made, the attraction of adhesion causes the liquid to rise in the tube a short distance above the level of the liquid outside the tube. The finer the bore of the tube, the higher will the liquid rise in it.

If the corner of a towel be allowed to remain for a short time in water, the towel, for some distance above the surface of the water will be found to be wet, the minute spaces between the strands of the threads having acted as so many tubes in which the water rises by capillary attraction.

Capillary attraction plays a very important part in nature; it enables the soil and rocks to retain water, it forms one of the means by which plants are supplied with their liquid food, and it is called into use in distributing some of the animal juices throughout the body.

Chemical Affinity, like gravitation, is an attractive force, and, like cohesion, acts only at imperceptible distances. But it is an *atomic* force; it acts, primarily, only between atoms, and when these atoms are of different kinds of matter, a substance is produced entirely different from either of the atoms.

The difference between affinity and cohesion is thus very apparent; cohesion increases the mass of a substance by adding together many minute particles of the same substance; affinity *produces a new substance* by combining still more minute particles of totally dissimilar substances.

Elements.—It has been said that an element or simple substance is composed of but a single kind of matter; that is, if an element could be broken up into its atoms, all the atoms would be exactly alike in all particulars. There are about seventy known elements; of these, fifty-five are called metals, such as *aluminium*, *calcium*, *potassium*, *iron*, *copper*, *gold*, etc. The remaining elements are called metalloids; some are solids at ordinary temperatures, such as *silicon*, *carbon* (charcoal), *phosphorus*, and *sulphur;* one is a liquid,—*bromine;* and others are gases at ordinary temperatures, such as *oxygen*, *hydrogen*, and *nitrogen*.

Compounds.—Every substance in nature is composed of one or more elements in a *free* state, or is a chemical combination of two or more elements. Such a combination produces a compound substance.

Air is composed chiefly of oxygen and nitrogen mixed together in the free states. *Water* is a chemical compound of the two elements, oxygen and hydrogen; *quartz*, or *flint*, of oxygen and silicon; *limestone*, of oxygen, carbon, and calcium; *bread*, *meat*, and most foods, of oxygen, hydrogen, nitrogen, and carbon, together with minute quantities of various other elements.

Oxygen is far the most abundant element on the earth. At ordinary temperatures it is a gas—colorless, tasteless,

and odorless, and a trifle heavier than air. Oxygen is essential to all life, both animal and vegetable.

Oxygen forms about $\frac{1}{2}$ by weight of all rocks of the earth.
" " " $\frac{8}{9}$ " " " " water.
" " " $\frac{1}{5}$ " " " " air.
" " " $\frac{5}{9}$ " " " " vegetable matter.
" " " $\frac{2}{3}$ " " " " animal matter.

Oxidation and Combustion.—The affinity of oxygen for most of the substances in nature is so strong that it is constantly combining with them when they are exposed to the air with its large quantity of free oxygen. The process is called "rusting," "rotting," or "burning" in different instances, all of which are covered by the general term *oxidation*. Oxidation always produces heat, as is the case with most chemical combinations. When the heat is great enough to produce light, the process is called *combustion*.

A familiar instance of oxidation is the "rusting" of iron in the air. The oxygen of the air unites with the surface iron to form the new substance, *oxide of iron*. The burning of fuel is really the same process, only the chemical affinity between the carbon and hydrogen of which most fuel is composed, and the oxygen of the air, is much greater than that between iron and oxygen; the heat produced by their union is great enough to produce light, and the process is consequently called *combustion*.

Decomposition is the breaking up of a compound into its elements or into simpler compounds. The affinity between different elements varies in strength. Whenever elements having a stronger affinity for each other than for those with which they happen to be combined, are brought by any means sufficiently close together for affinity to act, the weak combinations break up, and the elements, liberated by the decomposition, recombine according to the strength of their mutual affinities to form other substances, which, under similar circumstances, decompose

and recombine into still other compounds. In this way, the atoms and molecules are kept in circulation.

Gunpowder is nothing but certain weak combinations containing elements that have a strong affinity for each other, artificially placed so close together that a slight heat causes the weak combinations to decompose and leave certain of their ingredients free to unite in a strong combination.

Kinetic Energy.—One or more of these three great attractive forces — gravitation, cohesion, or affinity — is thought to be, directly or indirectly, the cause of all motion in the universe; and every one of the innumerable changes that are constantly taking place in matter around us, is thought to be the result of some kind of motion of that matter, — either a visible motion of its mass as a whole, or an invisible motion of its molecules or atoms. Matter in motion always imparts some kind of motion to other matter with which it comes in contact. This imparting of motion is called *doing work*. Matter in motion is, therefore, said to have the power to do work, or to possess *kinetic* (*active*) *energy*.

The quantity of work a body in motion is capable of doing,—or the amount of kinetic energy it possesses,—depends more upon the rapidity of its motion than upon its mass; for, while doubling the mass only doubles the energy, doubling the speed increases the energy four times; thus, energy *increases with the mass of a body but with the square of its velocity*. That is, a hundred-pound cannon-ball, moving with a certain speed, possesses no more energy than a one-pound ball moving ten times as fast.

Potential Energy.—It often happens that the expenditure of kinetic energy upon a body places it in such a position that, though not in motion, it would move and do work if unrestrained. A body in such a position is said to possess *potential* (*possible*) *energy*. A bent bow, a hoisted weight, or a wound-up watch spring possesses potential energy.

Potential energy is thus simply stored-up kinetic energy, since it exists only in bodies on which kinetic energy has been expended. Upon the removal of restraint, the body immediately moves, and the potential energy is converted back again into exactly the amount of kinetic energy which was expended in its production.

Conservation of Energy means that the total amount of energy in the universe is an unchangeable quantity. Energy, therefore, can not be created or destroyed, but it is constantly eluding observation by changing its form, or by entering and leaving different masses of matter. It is frequently *apparently* destroyed either (1) when it changes from a kinetic to a potential form,—as when the kinetic energy expended in lifting a heavy weight is changed into potential energy of the weight when the latter stops moving just before falling; or (2) when *masses in visible motion* impart a portion or all of their motion and energy to *invisible molecules*,—as when a falling weight strikes the earth, and its motion, *as a mass*, stops. In this case, if the weight and the place struck were carefully examined, they would be found to have undergone certain changes in consequence of the blow; they would be *hotter* than before, and they might have become luminous, or other changes might have taken place.

These changes—heat, light, etc.,—are simply the results of *molecular energy* arising from the invisible motions imparted to the molecules by the collision which stopped the visible motion of the weight. If the energy causing all the changes that occurred in consequence of the blow could be collected, it would be found to equal the amount which the weight possessed when it struck the earth, and *exactly this amount* of energy is passed on to other matter by the molecules before they regain their former condition.

Nature of Heat and Light.—Heat and light are the results of a certain kind of insensible motion of the molecules of matter. Therefore, all warm or luminous bodies possess kinetic energy by virtue of this motion. A body

is said to be hot when its molecules possess an exceedingly rapid, but of course invisible, vibratory motion. When the molecular motions increase to a certain rapidity, the body becomes *luminous*, and is said to be "red" hot. As the motions become slower, the body ceases to be luminous and becomes cooler, but the molecules of no body are supposed to be at rest. Hence all bodies, even the coldest, are thought to have more or less heat. Whatever increases the rapidity of the motions increases the heat of the body, and whatever decreases the rapidity causes the body to cool.

Repeated blows of a hammer on a nail, or the friction of one body rubbing on another, increases the rapidity of the molecular agitation in each, and thus *produces heat mechanically*. The clash of atoms colliding under the attraction of affinity, produces a similar increase, and produces *heat chemically*. The heat of all "fire" is thus produced.

Transference of Heat.—Unequally heated bodies, whether touching each other or not, always tend to acquire a uniform temperature, the hotter becoming cooler, and the cooler becoming hotter. This is accomplished (1) by radiation of energy; (2) by conduction; or (3) by convection.

Radiation of Energy takes place between unequally heated bodies that are not in contact. It is explained by supposing that the universe is pervaded by an elastic substance called *luminiferous ether*, so thin that it enters and completely fills the invisible interstices between the molecules of all substances as easily as water fills the cavities of a sponge. The movements of the molecules of all bodies tend to produce vibrations in the ether pervading and surrounding them, just as any shock sets a bowl of jelly in a quiver. The hotter bodies tend to impress quicker vibrations on the ether than the cooler ones. A continued

expenditure of energy (heat) is required to maintain the vibrations of the ether, which spread away or *radiate* in all directions; hence the body that excites the vibrations *cools;* but if the energy of the vibrations of the ether is expended upon, or *absorbed* by, a substance whose molecules are thereby excited to faster motion, the substance is warmed. Radiant energy is said to pass from one body to another in *rays.* Some of the rays emitted by very hot bodies are perceptible to the nerves of the eye as light; these rays have 392 trillion to 757 trillion vibrations a second. Rays of slower or faster vibrations are not perceived by the eye. Any ray that is absorbed by a substance, whether visible or invisible as light, produces heat.

It is by radiation of energy that the heat and light of the sun reach the earth, and that a person is warmed when standing before a fire. Radiant energy travels through ether at the enormous speed of 186,000 miles a second. The heat and light of the sun require about eight minutes to reach the earth.

Conduction.—When unequally heated bodies or molecules are so close together that they are usually said to be in contact—as the molecules are in *solids*—the more active molecules impart some of their motion to the slower moving adjacent molecules, and these to their still slower neighbors, until a uniform heat and rate of motion is *conducted* to the most distant part of the body. In comparison with radiation, the *conduction* of heat is exceedingly slow; but dense bodies, such as the metals, conduct heat faster than porous bodies, such as snow, earth, rock, etc. The former are therefore called good conductors, while the latter are called poor or non-conductors.

Convection.—Liquids and gases are very poor conductors, since their molecules can move freely among themselves. Hence, if the *upper* part of a liquid or gas is warmed, a *very* long time is required to transfer heat to

the lower portion; but if heat is applied from *below*, the lower portions generally expand as they grow warmer, and thus become lighter than those above. The lower portions are therefore forced to rise by the gravity of the heavier portions above, and thus *convection currents* are established, which convey the heat throughout the liquid or the gas.

Reflection, Absorption, and Transmission of Radiant Energy.—When radiant energy encounters a body, it (1) enters the body, or (2) is *reflected* from its surface. That which enters may be either *transmitted* through the body and pass out on the opposite side, or it may be *absorbed* (retained in the body). It is only the energy that is absorbed that affects the temperature of the body. Bodies are called good reflectors, absorbers, or transmitters of radiant energy according as they reflect, absorb, or transmit the greater part of the rays falling on their surface, though no body is perfect in either respect; the best reflectors absorb some of the energy, the best absorbers reflect a portion, and the best transmitters both absorb and reflect a little.

Bodies such as glass, which transmit most of the rapid vibrations of *visible rays*, are called *transparent*. Bodies which transmit most of the ether vibrations of either visible or invisible rays, without being themselves warmed, are called *diathermanous*. Bodies which absorb most of the ether vibrations, and are hence warmed, are said to be *athermanous*. Most bodies are athermanous, and none are perfectly diathermanous or transparent. Dry air and rock salt are among the most diathermanous substances. The dry, pure air of high mountains transmits nearly all the heat of the sun's rays, and is itself scarcely warmed by them. On account of this quality of the air, a person at the top of a very high mountain might be quite uncomfortably warm in the sunshine, and yet water might be freezing in the shadow of a rock beside him. Glass, and air rendered slightly hazy by fine water globules or dust particles, though diathermanous to light rays, are largely athermanous to rays emitted by dark bodies. Thus, the window-glass allows the sunbeams to enter and warm a room, but prevents the dark radiations from the warm interior from

passing out again. Water, though exceedingly transparent, transmits scarcely any dark rays.

Expansion and Contraction.—When a body grows hotter or colder, a change in its size *always* takes place. As a general rule, *bodies expand when heated and contract when cooled.*

In the ordinary thermometer, or heat measure, the expansion and contraction is employed to denote its change of temperature. The common thermometer consists of a glass tube of very fine bore, terminating in a bulb, which, with part of the tube, is filled with some liquid, usually mercury. As the temperature of the mercury increases, it expands and mounts higher in the tube; as the temperature decreases, the mercury contracts and descends in the tube. The tube is graduated by marking the height of the mercury when the bulb is held first in freezing and then in boiling water, and marking the intervening space into equal divisions called degrees. In Fahrenheit's thermometer, which is generally used in this country, the freezing point is marked 32° and the boiling point 212°. When the thermometer is brought into the neighborhood of a hot or cold body, the mutual radiation between the body and the instrument reduces them to a common temperature, which can at once be compared with that of freezing or boiling water by noting the height of the mercury in the graduated tube.

Fig. 4.

The power with which substances expand or contract is practically resistless. The amount of expansion or contraction varies in different substances; thus, for each degree of variation in temperature, a mass of air grows larger or smaller by about $\frac{2039}{1000000}$; water, $\frac{239}{1000000}$; ice, $\frac{68}{1000000}$; iron, $\frac{20}{1000000}$; and rock but $\frac{16}{1000000}$ of its bulk or volume. These amounts are so small as to be usually imperceptible, but when substances are in large quantity, or when the variation in temperature is great, the expansion or contraction is very perceptible; and, being resistless, the results are stupendous.

A change of temperature of 10° in a mass of air one mile square tends to change its length, breadth, and thickness by about thirty-six feet. A much greater change of temperature occurs daily through millions of cubic miles of the atmosphere. A change of only 1° in the temperature of a sheet of ice a mile long changes its length about 1¼ inches. A contraction of even this small amount accounts for the long, fine cracks which open with loud report in the ice of all ponds and lakes in cold weather. A part of the earth's rocky crust one mile in length would tend to become about 2¾ feet longer were its temperature increased 100°.

Explanation of Expansion and Contraction.—The expansion or contraction of a body results from a movement of its molecules into an arrangement occupying a greater or a less space. Cohesion usually resists such movements as result in expansion; hence, part of the heat-energy entering a body must counteract the resistance of cohesion, and is thus held in a potential or inactive form to maintain the altered *size* of the body, and only the remainder of the energy is left to cause the change in the active motion or quiver of the molecules, which alters the *temperature.* Conversely, when a body cools and contracts, it surrenders not only a portion of its active, temperature-maintaining energy, but also a portion of its potential, size-maintaining energy, which, being relieved of the resistance of cohesion, becomes active heat-energy as it leaves the body. The resistance of cohesion is very different in different substances; hence, the amount of heat-energy required to produce the same change of temperature varies greatly in different substances.

Water requires a greater amount than almost any other substance. Thus, if all the energy liberated in cooling a mass of rock 5° were to enter an equal weight of water, it would raise its temperature but 1°. Conversely, when a given weight of water cools 1°, it liberates enough energy to raise the temperature of an equal weight of rock 5°. Water is therefore said to have a capacity for heat, or a *specific heat,* five times as great as rock. The specific heat of water is about four times that of air.

On account of its great specific heat, water cools or is heated more slowly than almost any other substance. Thus, if a pound of water, at 50° temperature, is surrounded by a pound of air at 45° temperature, the water cools and the air becomes warmer until their temperatures are the same; but the water cools only 1°, for in doing so it liberates enough energy to heat the air 4°; hence, the resulting uniform temperature of air and water is 49°. The bulk of a pound of air is about 840 times larger than that of a pound of water; hence, a pond a foot deep, in cooling 1°, liberates enough energy to heat by 4° the overlying air to a height of 840 feet; thus, large bodies of water have a powerful influence upon the climate in their neighborhood.

Latent Heat.—All bodies require an exceptionally large amount of energy to effect the peculiar re-arrangement of their molecules when they change from a solid to a liquid, or from a liquid into a gaseous state. When a solid is heated, its size and temperature increase until it begins to melt; then, though heat is still applied, its temperature remains unchanged until all of it is melted, the entire energy of the heat being required to re-arrange the molecules into a liquid form. When this re-arrangement of all the molecules is completed, if heat be still applied, the size and temperature of the liquid increase until it begins to boil or pass into vapor. Here the same thing happens; although heat is applied continuously, all its energy is rendered potential by the resistance which cohesion offers to the alteration of molecular arrangement into a gaseous form, and the temperature remains unchanged until the liquid has entirely disappeared, after which the temperature of the gas begins to increase.

The energy which thus disappears upon the melting or vaporizing of substances, is said to become *latent* (concealed); for when the substance passes back again into a solid or liquid state upon cooling, the latent energy again appears as heat, which affects the temperature of surrounding bodies.

The latent heat of water is greater than that of most other substances. It requires as much heat-energy simply to melt a pound of ice—without changing its temperature in the least—as is required to raise the temperature of 140 pounds of water 1°, while the energy required to vaporize a pound of water would raise the temperature of 980 pounds of water 1°.

Freezing of Water.—Water, iron, and some other substances occupy a greater space in the solid than in the liquid state, and hence do not expand and contract according to the general rule *when near their melting points.* If fresh water be cooled, it contracts regularly till it reaches its *maximum density* at a temperature of 39°, after which it *slowly expands as it cools,* until, in freezing, it makes a sudden and great expansion—twelve cubic inches of water making about thirteen cubic inches of ice. Ice is consequently lighter than an equal bulk of water, and hence floats. If the ice be further cooled, it will be found to contract regularly. Hence, it is only during the change from the liquid into the solid state that the general rule of expansion and contraction is reversed.

This property of water is of great importance. Lakes and rivers cool in winter by radiating and conducting heat to the colder air. As the surface water cools and contracts, it sinks, and is replaced by warmer water from beneath, which in turn cools and sinks, until the whole depth of the water is reduced to 39°. Should this process continue until ice was formed, the ice, too, would sink, and accumulate at the bottom until the lakes and streams were converted into solid blocks of ice, which the heat of the succeeding summer could not melt. But, after reaching 39°, the water *expands* by cooling until after ice is formed. Hence, the ice-cold surface water and the ice are lighter than the deeper water, and form a floating blanket, which prevents to a great extent the escape of heat from the slightly warmer water beneath, and so preserves it in a liquid state through the winter.

Evaporation is the process by which many liquids and some solids pass into a gaseous state at temperatures far below their boiling points. Evaporation is almost con-

stantly taking place at the surface of every sheet of water, snow, or ice, as well as at every moist surface in the world. It is made strikingly manifest when a damp cloth is hung in the air, for in a short time the cloth becomes *dry*—that is, the moisture evaporates and passes off into the air in the form of invisible water-gas, or vapor.

Although evaporation takes place at temperatures much lower than the boiling point of water, the amount of energy rendered "latent" is about the same in both processes. Energy in the case of evaporation is supplied by the molecular motion of surrounding substances, which thus become cooler. This accounts for the sensation of cold when a rapidly evaporating liquid, as cologne or ammonia, is poured on the hand; part of the energy employed in maintaining the temperature of the hand is drawn upon to rearrange the molecules of the liquid and maintain it in a gaseous state; this energy thus disappears as heat, or becomes latent.

Mechanical Equivalent of Heat.—Exactly the same amount of energy is always required under similar conditions to increase the heat of a substance from one given temperature to another; and conversely, in cooling from a given temperature to another, a body always liberates exactly the same amount of energy. The amount of energy required to raise the temperature of a pound of water 1°, and to effect its corresponding expansion, is equal to that possessed by a one-pound weight striking the earth after a fall of 772 feet. This amount of energy is called the *mechanical equivalent of heat.*

The enormous energy of heat is thus made manifest: a cubic foot of water (62¼ pounds), can never be heated from the freezing to the boiling point except by the expenditure of enough energy to raise bodily a large locomotive engine and tender (43¼ tons) 100 feet high into the air; and whenever a cubic foot of water simply cools from the boiling to the freezing point, enough energy is liberated to accomplish this same enormous lift.

Refraction.—A ray of light passes through a transparent body in a straight line; but in passing *obliquely*

from any transparent body to another of different density, as from air to water, water to air, or air to glass, the path of the ray is bent from a straight course. This bending is called *refraction*.

Thus, suppose the ray *ab* (Fig. 5) to be passing obliquely from the air into the denser transparent substance, glass. At *b* part of the ray is reflected toward *g*; part is absorbed by the glass, and the rest is refracted in the direction *bc*. At *c* part of this is reflected back toward *h*, and the rest, upon re-entering the air, is again refracted in the direction *cd*. If the surfaces of the glass are not parallel, but form the sides of a triangular prism, as in Fig. 6, then the *incident* ray *ab*, from the candle, will be refracted in the direction *cd*. As objects appear in the direction from which the ray enters the eye, the candle *a* would appear to an observer at *d* to be at *x*. If the incident ray fall *very* obliquely on the refracting surface, it is *totally reflected* from that surface, and does not penetrate it at all. Thus, when a ray from an object at the bottom of a pond makes an angle greater than 48° 27′ with a perpendicular to the surface of the water, it does not enter the air, but is totally reflected from the surface toward the bottom again.

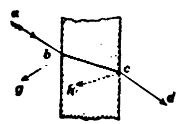


Fig. 5.

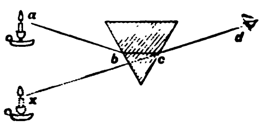


Fig. 6.

Diffusion of Light.—If a ray of sunlight enters a completely darkened room through a small aperture and falls upon a screen, (1) the path of the ray becomes visible from the illumination of the floating dust and air particles; (2) a bright white image of the aperture is formed on the screen; and (3) the light, reflected from the dust and air particles, and from the image on the screen, is diffused throughout the room, and the outlines of objects in it become visible.

Were it not for this general reflection and diffusion of light by the particles of the atmosphere, all shadows would be perfectly black, and all objects in shadow would be invisible.

The Spectrum.—If a triangular prism of glass be held in the ray between the aperture and the screen, the bright white image not only alters its position by the refraction of the ray, but it changes into an elongated, variously colored band (Fig. 7), the colors shading off imperceptibly from red at one end, through orange, yellow, and green, to a pale blue or violet at the other end. This colored band of light is called the *solar spectrum.*

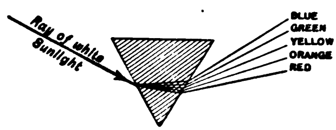


Fig. 7.

The spectrum is explained by supposing that the sensation of color depends entirely upon the rapidity of the ether vibrations or waves, which produce light. When the rate of vibration is 392 trillions to the second, the sensation of *red* is produced upon the eye. As the vibrations increase in rapidity, they give rise successively to each of the color sensations of the spectrum. If the rapidity of vibration increases beyond that which produces the sensation of violet (757 trillions to the second), the eye is not affected, and they cease to be luminous. A ray of sunlight is composed of vibrations of all degrees of rapidity which collectively produce a white or colorless sensation. By refraction, the ether waves of different degrees of rapidity are separated, the more rapid waves being bent, or refracted, more than the slower ones; thus, the elongated band or image is produced, each part of which reflects to the eye waves of a different rapidity, and hence produces different color sensations. The color of any object in nature depends upon the rapidity of the ether waves which it is able to reflect or transmit to the eye; thus, red glass absorbs the energy of all the luminous ether waves except that of the slowest, which it is able to transmit; these rays produce the red sensation, and the glass appears of that color. A leaf, in the same way, absorbs all ether waves excepting those which on reflection excite the green sensation. This absorption by different bodies of ether waves of certain length, and the transmission or reflection of those of other length, is called *selective absorption.*

Magnetism and Electricity are peculiar states or conditions of matter, probably of the luminiferous ether, pro-

duced by the expenditure of kinetic energy upon it. The exact nature of these conditions is very imperfectly understood, but many of the peculiarities which they induce in ordinary matter have long been recognized.

Under the influence of the magnetic condition, a body exercises an attractive or a repellent force upon other matter in its neighborhood, and is called a magnet. The neighborhood over which it exerts this force is called its *magnetic field.*

A kind of iron ore (lodestone) is always magnetic, and attracts certain substances. Small pieces of iron, for instance, will move to the lodestone over short distances, and adhere to it, and while under its influence are themselves magnetic. Soft iron, however, loses this quality upon the removal of the lodestone, and is, therefore, called a temporary magnet. Hard iron and steel, on the contrary, retain the magnetic properties of the lodestone, and become permanent magnets. Magnetism is said to have been imparted to these bodies by *induction.*

Poles of a Magnet.—The attraction of a magnet is not uniform throughout its length, but is greatest near its ends, which are called *poles.* Thus, if a magnet be laid among iron filings, they will adhere in great tufts to the ends or poles, but not to the center of the magnet. Whenever a body is magnetized, however small it may be, it exhibits this peculiarity of two poles, one at either end, with a region deficient in magnetism between them. One of the poles of magnets is called the positive (+), and the other the negative (—) pole, while the line joining the poles is called the *axis* of the magnet.

Law of Polar Action.—If a permanent magnet be delicately balanced on a pivot at the center, so that it may swing freely, and either pole of a second magnet be successively presented to its two ends, it will be found that like poles (two + or two — poles) *repel,* while unlike poles (a + and a — pole) *attract* each other.

Lines of Magnetic Force.—If one of the poles, say the + pole, of a strong magnet, be placed against the lower side of a horizontal plate of glass, on the upper side of which iron filings are scattered, the filings are magnetized by induction through the glass; and if the glass be lightly tapped, the filings tend to arrange themselves in lines radiating from the portion of the glass immediately over the pole of the magnet. These are called *lines of magnetic force.*

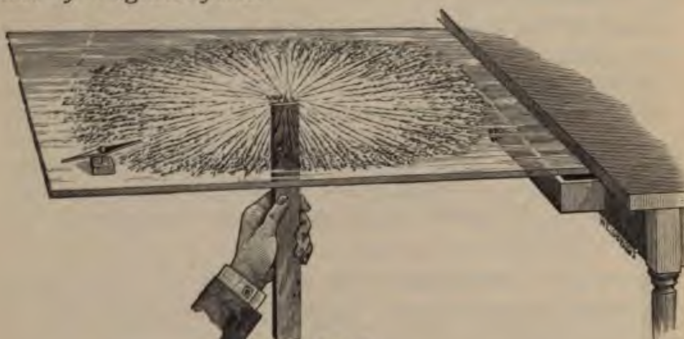


Fig. 8.

This is caused by the attraction of the magnet beneath the glass for the *opposite pole* of each iron filing, which has been rendered a temporary magnet by induction; hence, when the filings are jarred by the tapping on the glass, each points its greatest length or axis away from the locality of the bar magnet, thus producing the radiating lines. These are called lines of magnetic force, because, if a permanent magnet, freely swinging on a pivot at its center, be set upon the glass, it will settle to rest with its axis parallel with the line or ray beneath it, and its — pole pointed toward the + pole of the magnet beneath the glass. The same thing would have happened if the — pole of the bar magnet had been placed beneath the glass, excepting that in that case the opposite (or +) pole of the swinging magnet would have pointed toward it. (Fig. 8.)

The earth itself is a huge magnet; one of its poles is at present located beneath the northern part of North America, and the other beneath the antarctic regions

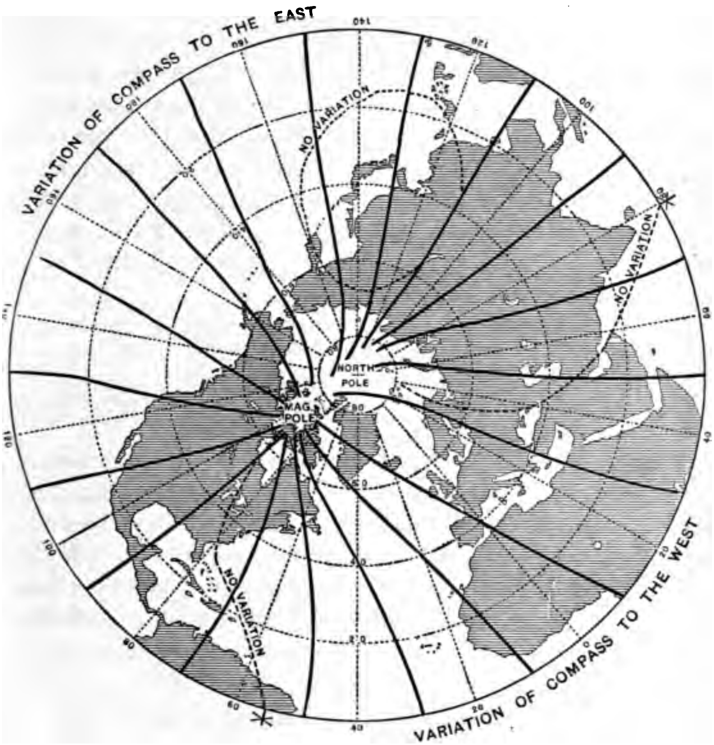


Fig. 9.—Magnetic Meridians in Northern Hemisphere.

south of Australia; but these poles very gradually change their position, though they seem to be confined to the arctic and antarctic regions respectively. The lines of magnetic force of this great terrestrial magnet are usually called *magnetic meridians*. The direction of the magnetic meridians in the northern hemisphere is represented by the heavy lines in Figure 9. Each of these magnetic meridians, like the lines of force in the iron filings, indicates the direction in which a freely swinging magnet will settle to rest at localities on that meridian.

Variation of the Compass.—The compass is essentially a freely swinging magnet. The pole of this magnet or "needle," which points to the magnetic pole in the arctic regions, is called its north or + pole. But the magnetic pole toward which the compass points, does not coincide with the end of the earth's axis or true north; hence, the compass needle does not every-where indicate a true north-and-south line; the angle which it makes with this line is called the *variation of the compass.*

The chart shows that the variation is considerably *west* of true north over most of the Atlantic and its coasts, but to the *east* over the Pacific and its coasts. Possibly in consequence of a slow movement in the magnetic pole, the west variation in the United States is now increasing, while the east variation is diminishing.

The cause of terrestrial magnetism is undetermined, but it is not improbable that it is induced by electricity generated in the luminiferous ether by the rotation of the earth. *Magnetic storms,* or unusual movements of the magnetic poles and meridians, producing sudden vibrations of the compass needle, and sometimes interfering with the working of telegraph lines, occur occasionally, and are most frequent at intervals of about eleven years—corresponding to times of great disturbance in the sun.

The electrical condition of matter is rendered manifest in many ways. When in this condition matter is almost always heated, and sometimes so highly heated as to become luminous. Quite frequently the electrified body becomes a temporary magnet; sometimes the body is thrown into sensible movement; sometimes the movement is insensible (molecular), but sufficiently violent to overcome cohesion, and thus change the state of aggregation of the body; at other times, the movement may be violent enough to overcome chemical affinity, and thus cause the decomposition and entire disappearance of the electrified substance. Very frequently the collision of dis-

placed molecules gives rise to sound. The sound may vary in intensity, from the scarcely audible crack of a small electric spark, to the deafening crash of thunder.

Development of Electricity.—The expenditure of energy in any manner and upon any substance seems to develop a greater or less amount of electricity; even the bringing into simple contact of any two substances seems to result in a more or less pronounced electrical condition in these substances.

As simple contact of two substances develops an electrical condition, this condition is constantly being developed in nature, but its effects are not always seen because many substances transmit electrical energy readily to the earth, where it quietly diffuses itself.

Conductors.—All substances transmit electrical energy, but in many substances its passage is almost instantaneous; such substances are called good conductors or *conductors*. Among them are the metals, liquids, and hence all moist bodies, including living animals and plants. *Non-conductors* transmit electrical energy with extreme slowness; such are glass, dry air, stone and earthy substances, and dry animal and vegetable matter.

An electrified conductor surrounded by non-conductors retains its electrical energy a long time, and is said to be *insulated*. If a piece of brass be electrified and held in the hand, its electrical energy passes through the body, imparting a more or less powerful shock, and escapes to the earth; but if the electrified brass rest on a glass plate, and is surrounded by dry air, it is insulated.

Positive and Negative Electricity.—Two kinds of electrical energy always make their appearance simultaneously when a body is electrified, and are respectively called *positive* and *negative electricity*. Each kind possesses a strong attraction for the opposite kind, but repels electricity of the same kind. It is convenient to conceive that both kinds of electricity exist in all bodies, but when present in equal quantities they neutralize each other, and

the body exhibits no electrical properties. By the application of energy, these electricities are conceived to be separated and kept apart, the body thus becoming electrified, positive electricity collecting at one extremity and negative at the other.

When a body is electrified, it always electrifies surrounding objects by *induction;* that is, the near neighborhood of an electrified body causes a separation of the two kinds of electricity in surrounding objects, negative electricity collecting on the side of the objects which are nearest to the positive end of the electrified body, and *vice versa.*

The Electric Spark.—Thus, there is a strong attraction between the electricity at either end of the electrified body and the opposite kind of induced electricity on the nearest surfaces of surrounding bodies. These electricities tend to unite, but the intervening air, being a non-conductor, resists their union. If the charge be sufficiently intense, however, the electricity forces a passage for itself, part of its energy being transformed, by the resistance of the air, into heat. This makes the air particles along its path *white hot* for the fractional part of a second, and produces a streak of white light through the air called an *electric spark.*

The more dense and dry the intervening air, the greater must be the electric charge which is able to penetrate it, and the more intensely luminous and streak-like is the resulting spark. When the air is very thin or rare, the passage through it of an electric charge produces a more or less feeble glow rather than a bright spark, and the glow is often beautifully colored. An electric spark is generally accompanied by a crackling sound, more or less audible, as the spark is larger or smaller. The sound is simply the clash of the air particles upon each other as the air suddenly expands and contracts under the great but instantaneous change of temperature produced by the passage of the electricity.

PART I.—THE EARTH AS A PLANET.

CHAPTER I.

THE SOLAR SYSTEM.

The heavens declare the glory of God; and the firmament showeth his handywork.—PSALM xix: 1.

Fixed Stars and Planets.—By attentively observing the stars at night, it will be seen that they appear to move slowly across the sky. Observations upon several nights will convince one that most of the stars move together, like bright spots in a solid, revolving sky. In consequence, the position of each star is fixed in relation to the others, and on this account they are called *fixed stars.* Occasionally stars and comets are seen whose apparent nightly movement across the sky is not in unison with that of the others; they shift their positions among the fixed stars from night to night, and are therefore called *planets* (wanderers). The sun is also a wanderer, and appears each morning during the year among a different group of the fixed stars.

The Solar System.—These movements led astronomers to suspect that the wanderers have a peculiar relationship to each other, and further investigation confirmed this suspicion, as it is proved that the planets and comets revolve about the sun, thus forming a separate group of heavenly bodies, much nearer to us than any of the fixed stars.

We call this separate group the *solar system.* It is probable that each of the fixed stars is really a sun, and the center of a separate system of planets, but so far from us that the planets are invisible.

The Sun is the largest and most important body in the solar system. Its shape, like that of all the planets, is globular, or ball-like, but it differs from the planets in temperature, its surface being much hotter than the hottest fire. The sun supplies the solar system with radiant energy, which becomes sensible as heat, light, and in other forms.

The sun has a diameter of more than 866,000 miles, and weighs about 760 times as much as all the planets put together. The sun is largely composed of matter in a gaseous state, many substances existing there in that form, with which we are familiar only as dense solids, such as the metals. It is thought that the heat of the sun is developed and maintained by the gradual contraction and condensation of its gaseous body, and to a lesser extent by its collision with very small solid planetary bodies called meteors.

Fig. 10.—Relative Diameters of the Sun and Larger Planets.

The Planets are bodies much smaller than the sun, around which, at different distances, they revolve, and from which they receive most of their light and heat. The path of a planet around the sun is called its *orbit.* The planets shine at night by reason of the sunlight which is reflected from their surface, while the sun and the fixed stars shine by their own light.

There are more than two hundred and fifty planets, of which eight are vastly larger than the rest. The large ones are named in

the order of their distance from the sun: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Mercury, Venus, Mars, Jupiter, and Saturn are frequently visible from the earth as remarkably large and brilliant stars. Uranus is so distant as to be barely visible to the naked eye, and Neptune can never be seen without a telescope. Most of the other planets are very small, and lie between the orbits of Mars and Jupiter. They are never visible to the naked eye, and are called *planetoids* or *asteroids*.

Satellites.—Several of the planets are attended by one or more smaller bodies called *satellites*, or moons, which shine by reflected sunlight, and revolve around their respective planets, as the planets revolve around the sun.


Fig. 11.—Donati's Comet.

Comets are planetary bodies which revolve about the sun in very elongated orbits. The mass of a comet is usually very small, but it is generally so widely distributed that its volume is often enormous. Comets shine chiefly by reflected sunlight, though some comets approach the sun so closely that they become sufficiently heated to shine by their own light also.

Comets are often composed of a comparatively small, dense, or solid nucleus, surrounded by a less dense cloud or *coma*. There is frequently, though not always, an extension of the coma on one side of the comet, which forms the "tail." The tail is composed of matter in a state of extreme tenuity, and is often thousands of miles in length.

Meteors. — Millions of small fragments of matter, possibly the débris of disintegrated comets, revolve about the sun. Many of them enter our atmosphere, in which case the friction of the air on the rushing fragment de-

velops enough heat to ignite the fragment and render it luminous as a *meteor*, or "falling star."

Meteors are generally entirely consumed in the air, but sometimes a remnant of one reaches the earth's surface as a mass of stone and metal called an *aërolite*. These foreign bodies show considerable diversities of composition; but in no case have they yet revealed the existence of any element not found on the earth.

The Nebular Theory.—The sun and all its planets seem to be composed of the same kinds of matter. They are all globular in form. They all have a spinning motion in the same direction. The planets all move around the sun, and most of the satellites around their respective planets in the same direction. The sun itself appears to be a very hot, gaseous body, which is gradually cooling and contracting in volume. These considerations have led to the *nebular theory* of the formation of the solar system. According to this theory, all the matter composing the various members of the solar system was once so hot that it existed as a single enormous cloud or *nebula* filling all the space within the orbit of the most distant planet. As the nebula cooled and contracted, it acquired a rotary or spinning motion, and threw off successive rings, each of which, cooling and contracting about its densest point, assumed at length the form of a spinning, globular planet, revolving about the parent mass of nebula, which we call the sun. Several of the planets, in cooling, are supposed to have thrown off secondary rings, which condensed into satellites, or moons.

The Earth, upon which we live, is one of the eight larger planets,—the fifth in point of size, and the third in point of distance from the sun. The earth is attended by a secondary planet, called the *moon*, which revolves about the earth as the earth revolves about the sun.

Shape of the Earth.—The earth is nearly round or globular in shape. If it were exactly round, its shape

would be that of a *sphere*, but as it is slightly flattened on two opposite sides, its shape is that of a *spheroid*. If a person stands in the midst of a vast plain, or on the deck of a vessel at sea, the surface of the earth appears to be flat, and stretches away in every direction to a line where it seems to meet the sky; this line is called the *horizon*.

The circular area embraced by the horizon enlarges as the observer ascends, but even from the greatest height ever attained by balloonist (Fig. 12), the visible portion of the earth forms such an exceedingly small proportion of its whole surface that the curvature is entirely imperceptible.

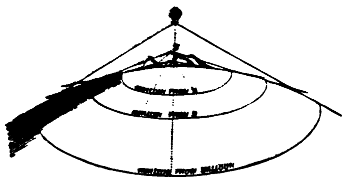


Fig. 12.

But the earth can not be flat, for mariners, by sailing continuously in the same general direction, have at last found themselves at their starting-point. That the surface is curved, is proved by the manner of disappearance of a ship upon reaching our horizon; first the hull, or body, of the vessel sinks out of view, then the lower sails disappear, and finally the highest parts of the masts sink beneath the horizon. That the curved surface is nearly that of a sphere is proved by the circular shadow which the earth invariably casts on the face of the moon at the time of a lunar eclipse. Now, a sphere is the only body which can cast no other than a circular shadow. Finally, very careful measurements upon the earth, and observations upon the fixed stars, have proved conclusively that the shape of the earth is *spheroidal*—but very nearly spherical—299 of the shortest diameters being equal to 298 of the longest diameters.

Fig. 13.

Size of the Earth.—The length of the shortest diameter of the earth is about 7,900 miles. The greatest diameter is about 26 miles longer. From these diameters, it follows that the greatest distance around the earth, or

An Eruption of the Volcano Vesuvius, near Naples, Italy.

its *circumference*, is about 25,000 miles, while the total area of the earth's surface is 197 millions of square miles.

These figures are much too large to convey a definite impression. The vastness of the earth may better be appreciated by considering that it would take a railway train moving a mile a minute, 17 days and nights of continuous travel to complete the greatest distance around it; and that there is room on its surface for fifty-five countries as large as the United States. Large as the earth seems to us, it is greatly exceeded in size by four of the other planets, while the surface of the sun has more than ten thousand times its area.

Fig. 14.—Relative Areas.

Internal Temperature of the Earth.—The occurrence in many localities of springs of hot, often boiling, water, and of volcanoes discharging steam and molten rock or lava, leads to the belief that the interior of the earth is very hot. Observations in mines, wells, and deep borings invariably indicate an increase of temperature with an increase of depth. The rate of this increase varies greatly in different localities, but the average is about 1° for every 50 feet. At this rate of increase, a temperature sufficient to melt any known substance would be attained at a depth of 30 or 40 miles.

The Density of the earth tends to confirm the belief in a very high internal temperature. Calculations prove that the earth weighs 5½ times as much as a similar globe of water. The surface rocks weigh from 2½ to 3 times as much as water. The pressure to which such rocks would be subjected at great depths would so greatly increase their density that we should expect the specific gravity of the whole earth to be much greater than 5½. There must be some expansive force within, which partially counteracts the pressure. Heat is the only force we know of that will do this.

Condition of the Interior. — The indications of a great internal heat, together with many facts in geology, lead many to believe that the earth is essentially a great globe of molten matter, on whose surface a cool, solid scum, or crust, has formed, which is comparatively thin— perhaps a hundred miles or more. Other phenomena have been held to indicate that the globe throughout is as rigid as steel. Those who hold this opinion believe it to be possible that the great weight of the overlying rocks may prevent expansion, which accompanies the liquefaction of all known rocks, and thus retain the interior of the earth in a solid form, at a temperature far above its melting point. Whether the great interior of the earth is or is not liquid by reason of its heat, it seems certain that the rocks at no great depth are capable of *flowing* as if they were plastic—like thick tar.

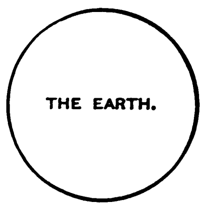


Fig. 15.—A Crust 100 Miles Thick.

This peculiarity would result from inequalities in pressure on adjacent regions. The weight of a few miles' thickness of the earth's crust is great enough to crush any known rock to powder, but a block of deeply buried rock can not fall to pieces as powder because of the side pressure of adjacent rocks. If, however, the pressure on any side should become less than that on the block, the latter would be more or less flattened, a portion of its substance being forced into the region of diminished pressure. Hence, no hollow places, caves, open cracks, or fissures can exist at great depths in the earth, for the enormous pressure would cause the adjacent rocks to "creep" or flow into the cavity and fill it.

CHAPTER II.

MOVEMENTS OF THE EARTH.

And God said, Let there be lights in the firmament of the heaven to divide the day from the night; and let them be for signs and for seasons, and for days and years.—GENESIS 1: 14.

Movements of the Earth.—The earth, which seems to us so solid and immovable, is really in constant and very rapid motion. It has a spinning motion, called *rotation*, on one of its diameters; and a much faster motion, called *revolution*, in its orbit around the sun.

We can not perceive these motions by observing objects in our neighborhood, because the whole earth moves along smoothly and noiselessly, carrying the atmosphere and all objects on its surface along with it. They thus preserve their relative positions as they would if the earth were at rest. It was only by carefully observing the sun and the fixed stars that it was discovered that their movements in relation to the earth are only apparent, and are caused by the movements of the earth itself.

Rotation.—The earth spins, or rotates, at a nearly uniform rate of speed, upon its shortest diameter, called its *axis*. The ends of the axis are called the *poles*. A line around the earth midway between the poles is called the *equator*. One of the results of rotation is the succession of day and night. The sun shines upon but one half of the earth at a time. The other half, being turned away from the sun, is in darkness. As the earth rotates, each point on its surface is carried successively into the light and into the darkness,

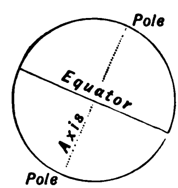


Fig. 16.

one day and one night, or about twenty-four hours, marking one complete rotation.

As the circumference of the earth is about 25,000 miles, and as the earth completes one rotation in twenty-four hours, it follows that a point on the equator moves at a speed of over 1,000 miles an hour. The speed of rotation is of course less at points on the surface nearer to the poles, and at the poles themselves is very slight; just as in a rotating wheel a point on the tire moves faster than a point on the hub.

Spheroidal Form of the Earth caused by Rotation.—The inertia of all rotating bodies gives them a tendency to fly away from the center. This tendency is called *centrifugal force*, and it increases with the speed of rotation; hence it is greater at the equator than toward the poles. In obedience to this force, the equatorial regions bulge out and the polar regions draw slightly nearer together, producing the *spheroidal form* of the earth.

Direction.—The earth always rotates in the same general direction, thereby affording the standard by which all terrestrial directions are determined. The direction in which the earth rotates is called *east;* it is nearly that in which the sun first appears every morning. The rotation of the earth to the east causes the sun and other heavenly bodies to appear to move across the sky in the opposite direction; this direction is *west.* If we stand with extended arms, facing east, our arms will be parallel with the earth's axis. The direction in which our left arm points is *north*, and the end of the axis in that direction is called the *north pole.* The direction in which our right arm points is *south,* and the end of the axis in that direction is called the *south pole.*

But the sun seldom rises *exactly* in the east, and it is therefore customary to reckon direction from the north, which can be accurately determined by observations on the North Star, or *Polaris*, a

fixed star situated almost directly over the north pole. For this reason it is often called the *Pole Star*. This star is of course only visible at places north of the equator, and can be found any clear night by reference to two stars, called "the pointers," in the constellation of "The Dipper." The north and south directions are in most places only approximately indicated by the compass (page 32).

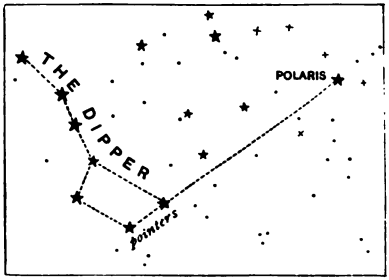


Fig. 17.

Location.—The earth always rotates upon the same axis; hence, the ends or poles of this axis mark two fixed points. Upon these two points depends a system of meridians and parallels, by means of which the location of any point on the surface of the earth may be exactly described.

Meridians are lines conceived to be drawn on the earth's surface directly from one pole to the other. Their direction is exactly north and south. Two meridians, exactly opposite each other, unite to form a *great circle*, which divides the earth's surface into an eastern and a western half, or *hemisphere*.

The Equator.—The position of the equator depends upon the positions of the poles, since it lies just half-way between them. Its direction is exactly east and west. The equator is also a great circle, and divides the earth's surface into a northern and a southern hemisphere.

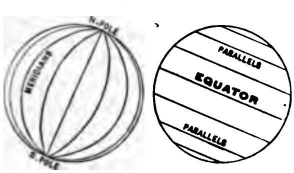


Fig. 18.—Meridians and Parallels.

Parallels are lines conceived to be drawn around the earth in the same direction as (parallel with) the equator. They thus extend east and west.

Parallels divide the earth's surface into unequal parts, and are called *small circles*.

Longitude is the angle which a meridian makes with some other meridian, assumed as the initial, or *standard*, meridian. Any meridian may be assumed as the standard, but the one passing through the observatory at Greenwich, England, is usually adopted. Longitude is reckoned in degrees and parts thereof, east and west from the standard meridian through 180° or half-way round the earth. Hence, the meridian of 180° east longitude coincides with the meridian of 180° west longitude. Longitude thus fixes the position of the meridian of any place on the earth's surface with respect to the standard meridian.

Since the meridians approach each other as they near the poles, the length of a degree of longitude decreases from the equator, where it is $\frac{1}{360}$th as long as the equator, or $69\frac{1}{6}$ miles, to the poles, where it is nothing. The longitude of a place is reckoned by observing the difference of time between that place and the standard meridian. The earth makes a complete rotation, that is, turns eastward through 360°, in 24 hours; hence, it turns eastward 15° in one hour, or 1° in four minutes. Therefore, at noon on a certain meridian it is four minutes *before* noon on a meridian 1° to the west, and four minutes *after* noon on a meridian 1° to the east. Noon may be approximately determined by observing when the sun is half-way between the eastern and western horizon. By comparing a watch keeping the time of the standard meridian with the noon at any place, thus determined, the difference of time is obtained. If the time by the watch is after noon, the longitude of the place is west, if before noon its longitude is east, of the standard meridian, and as many degrees as 4 is contained in the difference of time in minutes.

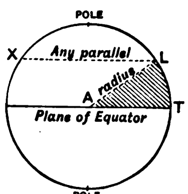


Fig. 19.

Latitude is the angle included between the radius of curvature of the earth's surface at any parallel and the plane of the equator. The angle LAT is the latitude of parallel LX. Latitude

is expressed in degrees and parts thereof, and is reckoned north and south from the equator to the poles, 90° north or south latitude corresponding to the north or the south pole respectively. Latitude thus fixes the position of any parallel with respect to the equator.

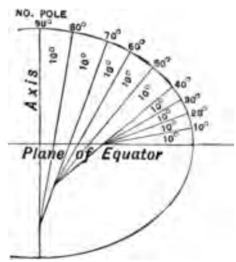


Fig. 20.

Degrees of latitude are $68\frac{7}{10}$ miles long near the equator, but they increase gradually toward the poles to a length of $69\frac{4}{10}$ miles. The reason for this slight increase is the spheroidal form of the earth. The convexity of its surface decreases from the equator toward the poles; therefore, the radius of curvature increases in the same direction. Two radii with the same degree of divergence are thus farther apart in polar than in equatorial regions, as indicated in Fig. 20, in which the spheroidal form of the earth is greatly exaggerated. Latitude may be reckoned by observing the angular distance between the horizon and the celestial pole. The celestial poles are points in the heavens directly over the poles of the earth or terrestrial poles, the approximate position of the north celestial pole being marked by the pole star *Polaris*. At the equator, where the latitude is zero, both the celestial poles lie *on* the horizon. As one travels from the equator toward one of these poles, the horizon sinks away from it, or the celestial pole seems to rise above the horizon. Half-way from the equator to the terrestrial pole, or in latitude 45°, the celestial pole is half-way to the zenith or 45° above the horizon. At the terrestrial pole, in 90° latitude, the celestial pole is overhead, or 90° from the horizon. Hence, the angular distance of the celestial pole above the horizon is the same as the observer's latitude or angular distance from the equator.

Practical Use of Longitude and Latitude.—Since longitude fixes the position of any meridian with respect to the standard meridian, and latitude the position of any parallel with respect to the equator, it follows, if the longitude and latitude of any place are known, the position of the place on the earth's surface is definitely fixed. Thus, if a place is in 77° 03′ W. long. Gr. and 38° 53′ N. lat., it

is known to be at the intersection of the meridian 77° 03′ west of Greenwich, with the parallel 38° 53′ north of the equator.

Revolution.—In addition to rotation, the earth has a forward movement through space in its orbit. The shape of the orbit is due to the action of two great forces. These are: (1) the gravitation of the sun, which tends to deflect the path toward that luminary; and (2) centrifugal force, which resists any deflection of the path from a straight line. As a result of these two forces, the orbit of the earth becomes nearly circular around the sun. The movement of the earth in its orbit is called its *revolution* to distinguish it from its movement of rotation.

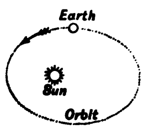


Fig. 21.

While *nearly* circular, the exact shape of the orbit is that of an ellipse, the sun being situated, not at the center, but at one of the foci. Owing to this fact, the distance from the earth to the sun varies about three million miles in different parts of the orbit. The mean distance is about 91½ million miles,—a distance which a railroad train, moving a mile a minute, would require 175 years to traverse.

Orbital Velocity.—It takes about 365¼ solar days for the earth to complete one revolution around the sun. This interval of time constitutes a *year*. In order to traverse its orbit in 365¼ days, the earth moves at the enormous velocity of nearly 1,100 miles a minute, but its speed is not uniform; it moves faster when nearest the sun (perihelion), and slower when most distant (aphelion).

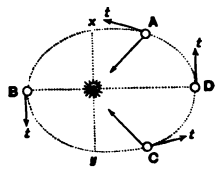


Fig. 22.

At each point of the orbit, *ABCD*, the inertia of the earth urges it in the direction of the tangents, *t*, (centrifugal force,) while gravity draws it toward the sun, *s*. At two points in the orbit, *B*, *D*, gravity acts at right angles to the centrifugal force, and neither adds to nor diminishes the speed, but only bends the line of

motion into a curve. At all other points gravity either increases or retards the speed; thus, at *A* it helps the earth forward. This increased speed adds to the centrifugal force, and not only enables the earth to resist being drawn into the sun, but, after passing *B*, to increase its distance from the sun. At *C*, however, gravity retards the speed and diminishes the centrifugal force, so that in the end gravity prevails and retains the earth in its orbit. The varying velocities of the earth are so nicely adjusted to its distance from the sun that the amount of heat it receives in passing through equal angular distances of its orbit are exactly equal, the greater velocity in perihelion just compensating the greater distance in aphelion. Thus, the 180° of the orbit, *xBy*, are nearer the sun, and hence hotter than the 180° *xDy*, but the amount of heat received by the earth is equal in each segment, since less time is occupied in passing over the former than the latter.

Fig. 23.

Inclination of the Earth's Axis.—The absolute direction of the earth's axis, at all points of the orbit, is nearly the same. This direction makes an angle of about 66½° with the plane of the ecliptic,—a plane passing through the earth's orbit and the sun's center. The axis, therefore, leans about 23½° (90°—66½°) out of a perpendicular to the plane of the ecliptic. This angle constitutes the *inclination of the axis*.

Zones.—The general distribution of the sun's heat over the earth's surface has occasioned its division into five belts, or *zones*,—a torrid, or hot zone, embracing the equatorial region; two frigid, or cold zones, including the region about either pole; and a temperate zone between the torrid zone and either frigid zone.

Any surface upon which the sun's rays fall perpendicularly is hotter than it would be if the rays fell obliquely, because more rays

fall upon it. Thus, *ab*, *cd*, and *ef* are equal spaces, and let *r* represent the parallel rays of the sun falling on them. It is seen that *cd*, upon which the rays fall nearly perpendicularly, receives almost three times as many rays as either *ab* or *ef* where they fall very obliquely. This fact explains why morning and evening are cooler than noon, *a* and *f* indicating the position of places with reference to the sun's rays in the morning and evening, and *cd* the position during the middle of the day; *ab* also indicates the position of regions near the poles of the earth, where the sun's rays *always* fall obliquely. Hence, these regions are much colder than those near the equator, where the rays fall obliquely only in the morning and evening.

Fig. 24.

The Tropics and the Polar Circles.—The lines bounding the zones are parallels of latitude: those bounding the torrid zone are called *tropics*, and those bounding the frigid zones are called *polar circles*. The position of these depends upon the inclination of the earth's axis.

In the diagram, *ABCD* represents the earth at four points in its orbit around the sun, *S*. At *A* the sun at noon is in the zenith of the equator *y''*. Each day, as the earth advances in its orbit, the inclination of the axis causes places farther and farther from the equator to be presented to the vertical rays of the noon sun, until, at *B*, the sun at noon is vertical over *z*, which is as far from the equator, *y*, as the north pole, *N*, is distant from *x*; that is, 23½°, or the angle of inclination of the earth's axis. As the earth passes onward in its orbit, the axis assumes daily a position in relation to the sun more nearly similar to that at *A*, and the earth presents to the vertical rays of the noon sun points nearer and nearer to the equator, until, at *C*, the sun is exactly over the equator again. Through the other half of the orbit the same phenomena take place, but on the other side of the equator. Thus,

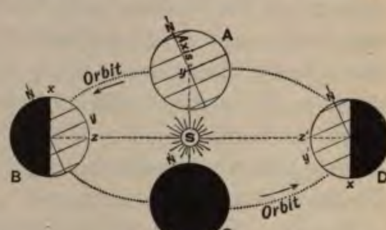


Fig. 25.

the only part of the earth which ever receives the vertical rays of the sun lies between the parallels of 23½° latitude on either side of the equator; hence, these parallels are taken as the limits of the hottest or "torrid" zone. The parallel on the north is called the tropic of Cancer, and the one to the south the tropic of Capricorn. They are called tropics (turnings), because over them the sun appears to turn and retrace his course toward the equator. It will be observed in the diagram that when the earth is at *B* or *D*, the region within 23½° of one of the poles is in darkness, and hence receives no light or heat during an entire rotation of the earth. These regions which, during at least one day of the year receive no heat rays, and during the rest of the year receive them only very obliquely, must be the coldest parts of the earth; hence, the parallels 23½° from the poles, or in latitude 66½°, are taken as the limits of the frigid zones. The polar circle near the north pole is the Arctic Circle; that nearest the south pole is the Antarctic Circle.

Length of Days and Nights.—Owing to the inclination of the earth's axis, there are but two points in the orbit where the light of the sun reaches both poles of the earth at the same time. These two points, (*A*, *C*, Fig. 25,) are called the equinoxes (equal nights), for when the earth occupies either of these positions in its orbit, the days and nights are every-where of equal length. At all other points in the orbit, as *B* and *D*, the light of the sun extends beyond one pole, but fails to reach the other. As a result, more than half of one polar hemisphere is illuminated, and its days are longer than its nights, while less than half of the other hemisphere is illuminated, and consequently in that hemisphere the days are shorter than the nights.

By referring to the last diagram, and remembering that the earth is constantly rotating upon its axis as well as moving around the sun in its orbit, it will be seen that the days and nights are always of equal length (12 hours) at the equator, but at all other places they are of unequal length, excepting when the earth is at the equinoxes. The days are shortest in the northern hemisphere and longest in the southern when the earth is at *B*. The reverse is the case six months later when the earth is at *D*. At these positions, called sol-

stices, it is continuous day at one polar circle, and continuous night at the other, during a complete rotation of the earth, or 24 hours, while at the poles it is either continuous day or continuous night while the earth is passing from *A* to *C*, or for six months.

The Seasons.—The succession of the seasons depends upon the revolution of the earth, together with the inclination of its axis. The earth is in the position *C* (Fig. 25) on the 21st of March. This is the *vernal equinox*, and the days and nights are every-where of equal length. As the earth moves forward in its orbit, the north pole begins to incline toward the sun, the days lengthen in the northern hemisphere and shorten in the southern; and, since the sun reaches the zenith of points north of the equator, the heat increases in the northern hemisphere while the cold increases in the southern. After 92½ days, or about June 21st, the sun reaches the zenith of the tropic of Cancer (*D*). This is the *summer solstice* in the northern hemisphere, which receives the sun's rays most perpendicularly, and the *winter solstice* in the southern hemisphere, upon which the sun's rays fall most obliquely. As the earth advances, the sun day by day reaches the zenith of points nearer the equator, and the days grow shorter in the northern hemisphere and longer in the southern. After 92½ days the earth reaches the *autumnal equinox* (*A*) about September 22. This is the beginning of spring in the southern hemisphere. Moving onward, the earth gradually presents its southern pole to the sun, while the north pole enters its annual period of cold and darkness. For 90 days the days in the northern hemisphere grow shorter until the *winter solstice* is reached about December 21 (*B*). This is the summer solstice, however, in the southern hemisphere, the time of its longest day and most direct exposure to the sun, which reaches the zenith of the tropic of Capricorn. Passing on

from this point in its orbit, the earth gradually withdraws its south pole from the sun until, after 90 days, it reaches the position of the vernal equinox again.

Projections.—It is impossible to represent with perfect accuracy the *curved* surface of the earth upon the *flat* surface of a map. Many arrangements, called *projections*, of the meridians and parallels, have been invented, each of which reduces to a minimum some one or more of the inevitable inaccuracies, while it may exaggerate others. When any feature of the earth's surface, therefore, is to be illustrated by means of a map, it is best to select from the many map projections one that is designed to show that special feature most accurately. Various maps in this book are thus drawn in three different projections: (1) *Mercator's*, (2) *Lambert's*, and (3) *Polar.*

In *Mercator's Projection* (Fig. 26), the meridians and parallels are straight lines crossing at right angles, and the spaces between them are so proportioned that any continuous direction on the earth's surface may be represented by a *straight line* on the map. Hence, every change in direction of any line on the map represents a corresponding change in direction of the line it represents on the earth's surface. Therefore, this projection is useful when *relative directions* in different parts of the earth are to be compared, as the directions of different ocean currents, etc. The *scale* of the map, however, is not uniform, but increases rapidly and irregularly from the equator toward the polar regions. Thus, Greenland is represented as larger than South America; whereas, it is really less than one eighth as large.

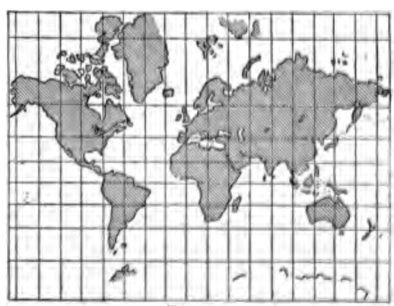


Fig. 26.

In *Lambert's Projection* (Fig. 27), equal areas on the map represent equal areas on the earth's surface. It may, therefore, be used

when areas are to be compared. The equator and the central meridian (not drawn in Fig. 27) of each hemisphere are straight lines drawn at right angles, but the parallels and all other meridians are dissimilar curved lines, the bounding meridians of each hemisphere joining at the poles to form circles. The space between meridians decreases toward the boundary of each hemisphere, but that between parallels increases in such proportion that all the subdivisions between any two parallels have the same area.

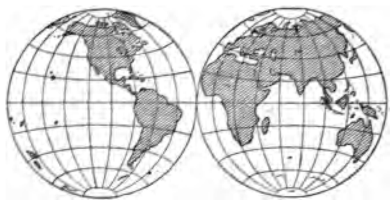


Fig. 27.

In *Polar Projection* (Fig. 28), the observer is supposed to be immediately over one of the poles of the earth, in the center of the map, and to be able to see at a glance the whole polar hemisphere from the pole to the equator (represented by the heavy circular line in the diagram). The parallels and the equator are indicated by concentric circles, and the meridians by straight lines radiating from the pole to the equator. This projection is specially adapted to show the true *relative position* of features on opposite sides of the same polar hemisphere. The two polar hemispheres may be separately shown in two circles having the north and the south poles respectively for their centers, and each terminating at the equator. The Isothermal and Isobaric charts (pages 63 and 85) are so drawn because these features form a complete system in each polar hemisphere, and may therefore be represented separately. But when features to be compared are not entirely embraced in one polar hemisphere, the whole surface of the earth may be shown in this projection, by dividing the concealed hemisphere into any number of equal sectors, extending from the equator to the pole, and arranging these as points around the equator.

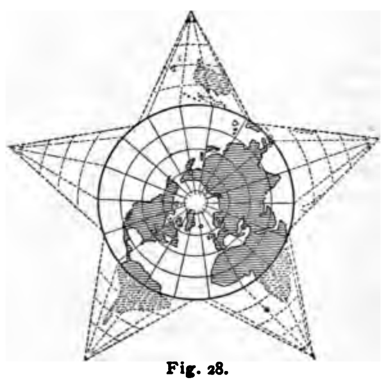


Fig. 28.

PART II.—THE ATMOSPHERE.

CHAPTER III.

COMPOSITION, WEIGHT, AND HEAT.

The Lord hath his way in the whirlwind and in the storm, and the clouds are the dust of his feet.—NAHUM 1: 3.

The Atmosphere is the outer covering of the earth. It is composed of a light and gaseous substance called *air*, and completely envelops the solid and liquid parts of the planet, filling the deepest depressions, and extending above the tops of the highest mountains.

Composition of Air.—Air is simply a mixture of several elements and compounds. The most important of these are the four invisible gases, nitrogen, oxygen, water vapor, and carbonic acid.

The Nitrogen and Oxygen form the great bulk of the atmosphere (about $\frac{29}{30}$ths of the whole) in the proportion of four measures of nitrogen to one measure of oxygen. The oxygen is the element useful to life. The nitrogen simply dilutes the oxygen.

Water Vapor is always present in the atmosphere. In extremely cold air its quantity is very minute, but in hot air it may form almost $\frac{1}{30}$th part of the whole. Vapor is supplied to the atmosphere by evaporation from moist surfaces, and is the source of clouds, rain, snow, hail, and dew.

Carbonic Acid is a compound of carbon and oxygen. It is given off to the atmosphere in the breath of animals, by the decay of animal and vegetable matter, and by the combustion of fuel. In amount it varies from 3 to 20 measures in 10,000 measures, but when present in the latter quantity the air is unfit to breathe, producing stupefaction, and eventually death. Plants are largely composed of carbon, which they obtain from the carbonic acid of the air, and thus prevent its undue accumulation in the atmosphere.

In addition to the above, there are generally present in the atmosphere traces of ammonia and of many other gases, besides multitudes of minute solid dust particles and microscopic living germs. The dust motes are visible when a ray of sunlight crosses a darkened room (page 27).

Weight of Air.—Although invisible and comparatively light, air is a veritable substance and has appreciable weight. This is made evident by the resistance it offers to the movements of an open fan, and, when it is itself in motion, by its effects upon the sails of a ship or a windmill. If a hollow glass globe holding a cubic foot is emptied of air and carefully weighed at sea-level, when the air is again let in it will be found to weigh about 1¼ ounces more than before. This increase is manifestly the weight of a cubic foot of air. An equal bulk of water weighs about 840 times as much. It is gravitation, or the *weight* of air, which holds the atmosphere to the earth, just as it is the weight of water which holds the oceans in their beds.

Pressure.—The weight, not of a cubic foot of air, but of the whole atmosphere resting upon any specified area, creates thereon a pressure called the *atmospheric pressure*.

The *Barometer* is an instrument used to ascertain the amount of atmospheric pressure. The barometer in most common use consists of a glass tube about three feet long, closed at the upper end and open below. The air being entirely taken from the tube, the

open end is immersed in a little basin of mercury (Fig. 29*b*). It is evident that the atmospheric pressure upon the exposed surface in the basin will force a column of mercury up into the vacuous tube, until the weight of the column becomes just equal to that pressure. When suitably mounted, as in Fig. 29*a*, there is attached to the tube a graduated scale for ascertaining the length of the mercurial column. The length of a column required to balance atmospheric pressure at sea-level is found to vary constantly, but on the average it is about 30 inches long; and since a column of mercury one inch square and 30 inches long weighs 14¾ pounds, it follows that this is the average weight, or pressure, of the atmosphere on each square inch of the earth's surface, *at sea-level.*

Fig. 29.

Density.—Being gaseous, air is elastic; even a slight pressure squeezes it into less space and renders it denser, but upon the removal of pressure, it immediately expands and becomes less dense. As every portion of the atmosphere sustains the pressure of the portion over it, the lower part is more heavily compressed than the upper. For this reason the atmosphere is densest near sea-level, and becomes less dense as the distance above that level increases.

Height.—The height or depth of the atmosphere has never been determined. Observations with the barometer indicate that with each ascent of about 3½ miles, one half of the former weight of the atmosphere is left below. The density decreases, of course, in the same ratio. At a height of 7 miles, the atmosphere is scarcely dense enough to sustain human life. At 50 miles it is no longer

dense enough to reflect the rays of the setting sun to cause twilight. But meteors have been observed at a height of 200 miles, and as they are caused by the rush of solid bodies through the *air*, the atmosphere, though greatly rarified, must exist at that elevation.

Since atmospheric pressure decreases with an increase of elevation, the mercury in a barometer falls as the instrument is carried upward. To moderate elevations, the rate of this fall is about $\frac{1}{10}$th of an inch for each 100 feet of ascent. The barometer may therefore be used to determine the relative heights of two or more places.

Uses of the Atmosphere.—Besides supplying oxygen to animal, and carbon to vegetable life, the atmosphere contributes to the habitability of the globe in three important particulars: (1) It accumulates the heat of the sun near the surface of the planet. (2) The condensation of its vapor is the only natural source of the world's supply of fresh water. (3) Its movements, or the winds, tend to equalize temperatures over the surface of the earth, and by its movements moisture is brought from the sea and distributed over the land.

Heat of the Atmosphere.—The sun may be regarded as our sole source of heat. The stars, the heated interior of the earth, the friction of meteors and of terrestrial bodies, chemical combinations, etc., are all sources of heat, but the combined amount so produced is trifling in comparison with that received from the sun, and may be disregarded.

How Imparted.—The heat of the sun is imparted to the atmosphere in four ways:

(1) *Directly.*—In their passage through the atmosphere the sun's rays lose about one third of their heat. This is absorbed by the atmosphere and raises its temperature.

(2) *Contact.*—About two thirds of the energy of the sun's rays are not absorbed in its passage through the atmos-

phere. This energy reaches the earth's surface and raises its temperature, and evaporates water. Contact with this warmed surface warms the lower atmosphere.

(3) *The liberation of latent heat* upon the condensation of vapor makes the surrounding air somewhat warmer than it otherwise would be.

(4) *Radiation from the earth's surface.*—The earth's surface, being warmed by the sun's rays, immediately radiates heat back toward space, but these slowly vibrating rays from the earth have not the penetrative power of the rays of the sun, and are largely absorbed by the lower atmosphere, which is thereby warmed (page 21).

The atmosphere thus causes heat to accumulate near the earth's surface; it allows a great portion of the sun's rays to enter, but retards the escape of heat. Without this property of the atmosphere no life of any kind could exist on the earth's surface, since its temperature, even under the direct rays of a tropical sun, would probably never rise above zero.

Distribution of Temperature.—Since the atmosphere is warmed by contact with and radiation from the earth's surface, the lowest portion of the atmosphere is the warmest; and the warmest part of the lower atmosphere is the part over the warmest portions of the earth, or the portions in the neighborhood of the equator. There is, therefore, a vertical and a horizontal variation of atmospheric temperature.

Vertical Variation.— Many observations of temperature made at various elevations in different parts of the earth, indicate that the atmosphere grows colder at the average rate of 1° Fahrenheit for each 300 feet of increased elevation.

Horizontal Variation.—Since the sun is vertical over the northern hemisphere in our summer, and over the southern hemisphere in our winter, the amount of heat received by either hemisphere during the two seasons is

very different. In both hemispheres the temperature decreases from equatorial toward polar regions, but the decrease is much more rapid on some meridians than it is on others.

This irregularity is caused by the different effects of heat upon land and water, owing to their differences (1) in specific capacities for heat, (2) in penetrability for heat rays, and (3) in state of aggregation, one being a solid and the other a liquid.

Specific Heat.—It has been stated (page 23) that the same amount of energy produces different changes of temperature in different substances. Now, a water surface requires nearly twice as much energy to raise its temperature by a given amount as an equal area of land; that is, if equal surfaces of land and water, at the same temperature, are equally exposed to the rays of the sun, the land will be warmed nearly twice as much as the water.

Penetrability.—The solar rays can not penetrate deeply into the solid land; and, as land is a very poor heat conductor, all the sun heat received is confined to a thin surface stratum. This stratum is thus quickly and strongly warmed, and heats the overlying air in contact with it. But during the night, when the source of heat is withdrawn, the thin surface stratum of the land and its overlying air lose their heat by outward radiation with almost equal rapidity. Solar rays affect water, however, to a depth of about 500 feet, and warmth is thus distributed throughout a comparatively thick layer, whose temperature, therefore, does not rise so high as that of the thin stratum of land. During the night the water surface cools more slowly than the land, for as soon as the surface becomes cooled in the slightest degree it contracts, becomes heavier, and sinks, being replaced by the warmer and lighter water from beneath.

The difference between the temperature of land and water is increased by the evaporation from the water surface, sensible heat of the water and overlying air becoming latent. Fully one half the sun heat falling upon the oceans is thus rendered insensible, while *none* of the heat falling on dry land becomes latent. Much of the heat rendered latent at the surface of the ocean is liberated over the land on the condensation of the vapor into clouds and rain, and thus warms the upper land air at the expense of the lower ocean air. Another reason why the sea is heated and cooled more slowly than the land, is that the ocean air generally contains more moisture than land air. The more moisture air contains the more impenetrable it is to solar rays (page 22). The air over the sea, therefore, stops and radiates back more of the entering sun heat during the day and more of the escaping surface heat during the night than does the drier land air.

State of Aggregation.—The solid land is stationary, and retains or radiates its heat in the same place where it is received. Water, however, is susceptible of being moved in currents, and thus of receiving heat in one place and losing it in another. Ocean currents carry warm water toward the poles and return cold water to the equator; thus nearly one half the heat received by the torrid zone is conveyed into higher latitudes.

Isothermal Charts.—If upon a map all places having the same mean temperature are connected by lines, such lines are called *isothermal* lines or simply *isotherms*. Taken collectively, these lines indicate the distribution of mean temperature over the region embraced in the map. Such a map is called an isothermal map or chart. On the accompanying isothermal charts the regions in which the temperature is higher than 70° are tinted pink, those in which it is lower than 30° are tinted blue, while those having a temperature between 30° and 70° are untinted.

Northern Hemisphere in Winter.—It will be seen on the chart that in temperate and polar regions the land air is colder than the sea air in corresponding latitudes, the

isotherm of 30° Fahr. descending to the neighborhood of 40° latitude over the land, while over the sea this isotherm lies in much higher latitudes, for the land at this season loses more heat by radiation during the long nights than it receives during the short days, but the sea loses less heat by radiation and is constantly receiving heat by warm currents from the equator. The difference in temperature is greater near the parallel of 60° than in any other latitude, amounting to about 47° Fahr. In equatorial regions the land air is slightly warmer than the sea air; thus, a temperature of more than 80° Fahr. prevails over equatorial Africa and South America, while a temperature of less than 80° Fahr. prevails over equatorial oceans, for currents carry heat away from the seas of these regions, while the diurnal loss and gain of heat are about equal on the land, since the nights and days are of nearly equal length throughout the year.

Northern Hemisphere in Summer.—During the long days of summer the land receives more heat than it radiates during the short nights, and thus accumulating heat, becomes in all latitudes warmer than the sea surface in corresponding latitudes. The difference in temperature is not great, however, because the sea absorbs heat by day as well as the land; and besides, in higher latitudes, it is constantly receiving heat in warm currents from lower latitudes. The difference amounts to about 18° Fahr. near the parallel of 60°, and to but 25° Fahr. where it is greatest,—near the parallel of 40°.

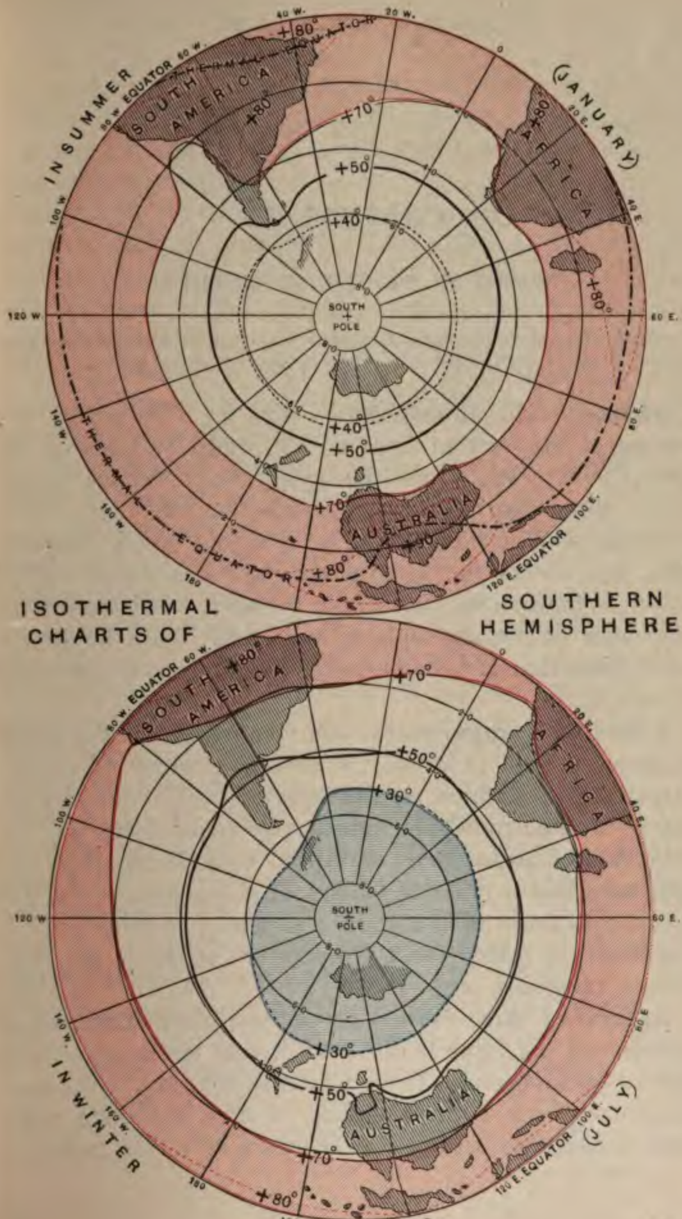
In the Southern Hemisphere, the distribution of temperature is seen to be much more regular than in the northern hemisphere, because its surface is more nearly uniform, being almost entirely water beyond 30° south latitude. The only considerable irregularity in the isotherms occurs in tropical regions, in the neighborhood of the

ISOTHERMAL CHARTS OF NORTHERN HEMISPHERE

land surfaces. Here, as in corresponding regions in the northern hemisphere and for like reasons, the land is slightly warmer than the sea surface at all seasons.

General Deduction.—It is thus seen that the water surface is not warmed so greatly during the day or during the summer, nor is it cooled so much at night or in winter as the land surfaces; therefore, *a water surface tends to preserve throughout the year a uniform temperature in its overlying air, while the air over the land may become both extremely hot and extremely cold.*

The Thermal Equator.—The line along which the greatest heat on the earth's surface occurs is called the *thermal equator.* As the sun is nearly vertical over the southern tropic in January, and over the northern tropic in July, it might be expected that during the year the thermal equator would travel backward and forward with the sun between these parallels. The different powers of land and water for accumulating and retaining heat, however, greatly modify its annual journey. In July (page 63) the high temperature of the great land surfaces carries the thermal equator to between 20° and 30° north latitude over the continents, while, in consequence of the slower change of temperature of the water surfaces, it lies in the neighborhood of only 10° north latitude over the oceans. In January, the summer of the southern hemisphere (page 65), the influence of the larger land masses to the north is still great enough to hold the thermal equator very near the geographical equator in the southern hemisphere, while the western extensions of Africa and South America prevent it from crossing into the southern hemisphere at all in those regions.


IN SUMMER
(JANUARY)
SOUTH AMERICA
AFRICA
AUSTRALIA
SOUTH POLE
THERMAL EQUATOR
EQUATOR
+80°
+70°
+50°
+40°
ISOTHERMAL CHARTS OF SOUTHERN HEMISPHERE
IN WINTER
(JULY)
+30°
120 W.
60 E.
160 E.
140 E.

CHAPTER IV.

MOISTURE OF THE ATMOSPHERE.

All the rivers run into the sea; yet the sea is not full: unto the place from whence the rivers come, thither they return again.—ECCLESIASTES 1: 7.

Source.—The atmosphere obtains its moisture by the process of evaporation from all the moist surfaces of the earth, but mostly from the great moist surface which covers three quarters of the globe—the sea.

Vapor.—Water ceases to be a liquid upon evaporation, and enters the atmosphere as a gas called *vapor*. Vapor is transparent, and hence invisible. It is only after the vapor of the atmosphere condenses into a liquid (or solid) form that it becomes visible; *as vapor it can never be seen.*

Effect of Temperature.—A volume of air at a given temperature can hold only a certain quantity of vapor; if this air be warmed, it can hold a greater quantity of vapor; if it be cooled, its capacity for vapor decreases. A cubic foot of air at a temperature of zero (Fahrenheit) can hold only half a grain of vapor; at a temperature of 32° it can hold more than 2 grains; at a temperature of 60° it can hold 5¾ grains; at a temperature of 90° it can hold almost 15 grains, etc.

Saturated Air.—When air at any given temperature contains all the vapor it can hold at that temperature, it is said to be *saturated*. If air which is not saturated comes in contact with a moist surface, it may evaporate water until it becomes saturated. If saturated air is cooled, it

can no longer hold all of its vapor; a portion of it, therefore, condenses into very small globules of water, or (if the temperature be low enough) into minute crystals of ice, and becomes visible.

Effect of Evaporation and Condensation.—The immediate effect of evaporation is to make all bodies in the immediate vicinity colder, or to retard their growing warmer, sensible heat being abstracted from these bodies and converted into latent heat. Condensation warms surrounding bodies, or retards their cooling, since the latent heat again becomes sensible heat as the vapor passes into the liquid or solid form.

General Distribution of Vapor.—Evaporation and condensation are constantly going on in nature, and therefore the amount of vapor in the atmosphere is constantly changing; but as warm air has a greater capacity for vapor than cold air, it is generally true that the amount of vapor in the air decreases from the surface of the earth upward, and from the equator toward the poles. It is estimated that almost one half the vapor in the atmosphere occurs lower than a height of one mile from the sea-level, and that fully nine tenths occur lower than four miles.

Relative Humidity.—Since the capacity of air for vapor varies so rapidly with temperature, the *absolute humidity*, or amount of vapor present, gives no definite idea of the dampness of the air, for the amount of vapor which saturates air at 60° temperature and makes it feel very damp, is but little more than one third of the amount required to saturate air at 90° temperature; with this amount of vapor present, air at the latter temperature feels excessively dry and evaporates water with avidity. It is therefore common to determine the proportion which the vapor present at any temperature forms of the amount which would saturate the air at that temperature. This

is called the *relative humidity* of the air. Thus, if the relative humidity is 25%, 50%, or 75%, the air contains ¼, ½, or ¾ of the vapor it is capable of holding at its temperature. Since air loses its capacity for vapor by cooling, it follows that when air is cooled its relative humidity increases, until, when cooled to the point of saturation, its relative humidity is 100. Any further cooling would produce condensation. Thus, since temperature decreases as the elevation above the earth's surface increases, evaporation may be taking place in the lower part of a mass of air, while condensation is in progress in the upper part.

The relative humidity is determined by means of an instrument called a *Hygrometer*. The hygrometer in most common use consists of two ordinary thermometers, the bulb of one of which is covered by a small piece of cloth kept constantly moist. The evaporation from this moist surface makes the bulb it covers colder than the other bulb, and the two thermometers register different temperatures. If the air is dry, evaporation is rapid and this difference is great; if the air is moist, evaporation is slower and the difference in temperature is less. Tables have been prepared from which the relative humidity corresponding to each degree of these differences between the "wet and the dry bulb thermometers," at any temperature, may at once be obtained.

Mist or Fog is a vast multitude of minute globules of water in the air near the earth's surface. Fog may be produced by the spray thrown off by falling or otherwise violently agitated water, but it is usually caused by the cooling of saturated air, and the consequent condensation of a portion of its vapor.

In winter, when our warm, moist breath passes from the mouth into the cold air, it is chilled, and a portion of its vapor condenses into a visible mist. Mists frequently form over sheets of water in summer nights, because the neighboring land cools at night faster than the water, and thus cools the atmosphere in contact with it; this, in turn, chills the moist air over the water below its point of saturation, causing part of its vapor to condense into a mist. When the heat of the sun in the morning increases the capacity of

the air for vapor, the mist evaporates and disappears. Mountain tops are frequently enveloped in mist because air currents, striking the mountain sides, are forced up the slopes into higher regions of the atmosphere, and thereby chilled below their point of saturation. The solid particles, or dust motes, in the air are great promoters of the formation of fogs, since they may radiate heat faster and thus become colder than the surrounding air, which is slightly cooled by contact with them. When this is the case, it is probable that each mist globule is formed around a dust mote.

Clouds are merely fogs formed at some distance above the earth's surface. Clouds may be formed by radiation between warm and cold currents of air, but the chief causes of their formation are the *mechanical cooling* of an ascending current of air, and the cooling by radiation of a poleward-moving current of air.

As air ascends and is relieved of a portion of atmospheric pressure, it expands, and pushes aside the surrounding air. In thus doing work, some of its energy must be expended; that is, the velocity of its molecules is decreased, and it is cooled. Therefore, when air ascends it becomes constantly cooler. The reverse occurs when air descends; the air is compressed by the increased atmospheric pressure, and work is done upon it, whereby the velocity of its molecules is increased, and the air becomes warmer. Until its point of saturation is reached, ascending air is thus *cooled* 1° *for each* 183 *feet of ascent*, but saturated air is cooled more slowly, owing to the effect of the liberation of latent heat on the condensation of its vapor. As descending air grows warmer its vapor does not condense, and therefore both dry and moist air grow 1° *warmer for each* 183 *feet of descent*.

Height of Clouds.—Since most of the vapor occurs in the lower part of the atmosphere, clouds are most common at no considerable altitude. The mean elevation of clouds in the temperate zones is about one half a mile, while the highest clouds ever seen are probably within ten miles of the earth's surface.

For convenience of description, clouds have been divided into three great classes, which are named from their general shapes:

Cirrus. Cumulus. Stratus. Nimbus.

Fig. 30.—Classes of Clouds.

cirrus, or feathery clouds; *cumulus*, or heaped-up clouds; and *stratus*, or spread-out clouds.

(1) **Cirrus** are the highest of all clouds. They are seen in fair weather as little, white, feathery patches in the blue sky. These clouds are so high that their temperature must be below the freezing point, and they are consequently thought to consist of minute ice crystals.

(2) **Cumulus** are the familiar, dome-shaped masses of cloud having generally nearly horizontal bases. They are formed by ascending currents of air, the horizontal base of the cloud marking the altitude where the decreasing temperature begins to condense the vapor of the ascending air.

(3) **Stratus** are the continuous, horizontal layers of cloud, of general uniform thickness. They are the lowest clouds, and frequently appear in the morning and evening of fine days as a low, foggy canopy overspreading the whole or a part of the sky, and disappearing as the heat of the day increases. All low, detached

clouds which look like lifted fog and are not consolidated into definite form, are stratus clouds.

By the various combinations of the three principal classes of clouds are obtained the *cirro-stratus*, or "Noah's ark" clouds; *cirro-cumulus*, or "a mackerel sky"; *cumulo-stratus*, or rain-threatening clouds; and *nimbus*, or the rain-cloud proper.

Clouds are spoken of as suspended in the air, but their globules are generally descending slowly through the force of gravity. They generally do not descend far, however, before they reach warmer regions of the atmosphere, where the lower portion evaporates and disappears. This accounts for the rapid change usually observed in the shape of clouds. Some portions of the cloud are disappearing by evaporation, while other parts are forming by condensation.

One of the chief uses of clouds is the assistance they render in maintaining an equable temperature at the earth's surface. In its liquid form, moisture obstructs the passage of heat rays much more than in its vaporous form. Clouds, therefore, stop much of the sun's heat, and so prevent the earth from becoming too hot during the day-time; while, by absorbing and radiating back a portion of the heat which is constantly streaming off from the earth, they prevent its surface from becoming too cold at night. This is the reason why cloudy days are generally cooler, but cloudy nights warmer, than fair ones.

Rain.—When a cloud is of considerable thickness, and the air beneath is nearly saturated, the globules in their gradual descent through the cloud unite to form larger drops, which, acquiring greater weight with their increase in size, descend faster than they evaporate; and, if the temperature be above the freezing point, may finally reach the earth as *rain*.

Rain-water.—When water evaporates, all impurities are left behind; vapor, therefore, condenses into absolutely

pure water; but all the gases which compose the air are soluble in water, and hence *rain-water*, when it reaches the earth, is never pure, being always more or less impregnated with these gases, and containing besides dust motes and other solid particles which it has picked up in its descent through the air.

Uses of Rain.—Rain, therefore, in addition to supplying the rivers, springs, and wells of the earth with water, performs an important office in washing and purifying the air and rendering it more healthful.

Snow.—If the temperature of a cloud is below the freezing point, the cloud is composed of minute ice crystals instead of water globules. If the air beneath such a cloud is nearly saturated and of sufficiently low temperature, the ice crystals of the cloud accumulate in their descent into flakes, which may reach the earth. We call this phenomenon *snow*.

Shape of Snow-flakes.—When snow-flakes are formed in calm air, they arrange themselves, according to the laws of the crystallization of water, into little six-sided plates or six-pointed stars. Although over a thousand different shapes have been observed in snow crystals, each shape adheres to the general law of six-sidedness.

Sleet.—When driven about by wind, the flakes lose this delicate arrangement, and when the temperature is such that the snow reaches the ground in a partly melted condition, it is called *sleet*. In the interior of continents the ground in winter is usually colder than the air, and the sleet upon reaching it immediately freezes, incasing the ground and vegetation in a coating of clear ice. This seldom happens on coasts and islands, where the moister air prevents the excessive cooling of the ground. In such localities, the continued melting of the sleet in the lower air gives it the appearance of a fine, driving rain.

Snow-storms are more frequent, and the snowfall is heavier when the temperature is near the freezing point than when it is much colder, because the colder air has so slight a capacity for vapor that it can yield but very little moisture to form snow.

Snow Line.—Since the atmosphere grows colder with increase of elevation, there must be some altitude where the temperature seldom rises above the freezing point, even in summer. Above this altitude, the moisture of

Fig. 31.—Some Shapes of Snow Crystals.

the air is usually precipitated in the form of ice or snow, and if the precipitation is moderately heavy, the snow never entirely disappears from the ground. The lower limit of this region of perpetual snow is called the *snow line*. The snow line is higher in equatorial than in polar regions.

The mean altitude of the snow line at the equator is about 16,000 ft.

In the mountains of Spain,	37° N. lat., its altitude is about	11,000 "
In the Swiss Alps, . . .	47° N. lat., " " " "	9,000 "
In Norway, ...	62° N. lat., " " " "	5,000 "
In Lapland, ...	69° N. lat., " " " "	3,300 "
In Bären Island, . . .	75° N. lat., " " " "	600 "
In Spitzbergen, ...	80° N. lat., it sinks nearly to sea-level.	

Uses of Snow.—One of the chief uses of snow arises from the fact that it is a very poor conductor of heat. A layer of snow in winter acts as a blanket, preventing the loss of the earth's heat by radiation, and keeping the ground soft and moist; but the soil and vegetation left exposed lose their heat by radiation, and are frozen hard and stiff.

Hail.—Pellets of ice falling in showers are called *hail.* These pellets, or *hailstones,* vary from the size of small shot to that of hens' eggs. Hailstones are sometimes composed throughout of clear ice, but usually there is a nucleus of hard, compact snow, surrounded by alternate layers of ice and snow. Hail is more common in summer than in winter, and in hot than in cool weather. It frequently precedes or accompanies a thunder shower.

Hail is now believed to be caused by the rapid ascent and consequent rapid cooling of quite warm, moist air. Below a certain height the vapor condenses into cloud and rain, but above that height into snow. The rain drops carried aloft by the powerful current of air are frozen into clear hailstones of the ordinary size, which, upon being thrown outward beyond the influence of the ascending current, fall to the earth. The snowy nucleus of other hailstones is supposed to be formed as a minute snowball above the region of rain, and, in descending, to be several times drawn into the ascending current and repeatedly carried aloft before it reaches the earth, each time receiving a layer of ice in the region of rain, and of snow in the higher regions.

Dew differs from fog or cloud in being little globules of water condensed from the atmospheric vapor, not in the air, but upon cool, solid bodies which have chilled the adjacent air below its point of saturation.

If, in a warm room, a tumbler be filled with ice water, the outside of the glass will in a few minutes be clouded over with myriads of tiny water globules. These are in every way analogous to dew, and are caused by the chilling of the air adjacent to the cold glass, and the consequent condensation of its vapor upon the outside of the

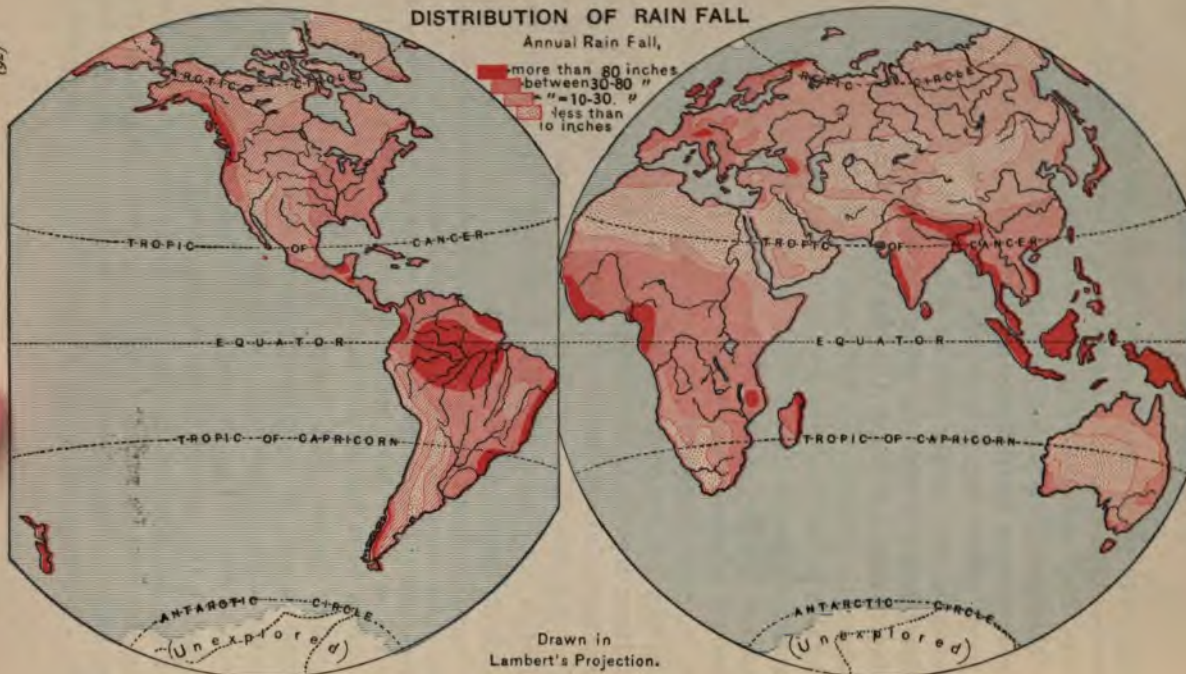
glass. The flitting cloud seen on a polished knife blade when breathed upon, is similarly caused by its momentarily chilling the warm breath and condensing part of its vapor.

Natural Formation of Dew.—At night the earth radiates more heat than it receives, and becomes cooler. Clouds absorb and reflect back most of this heat, and so maintain the temperature of the earth throughout the night; but if the sky be clear, the temperature of surface objects may fall below the point of saturation of the adjacent air. When this happens, the excess of vapor in the thin layer of air next to the objects condenses into tiny water globules, which unite into dew-drops upon such cold surfaces as leaves and grass blades. As dew is thus formed as soon as the temperature of the air sinks below its point of saturation, the temperature of the point of saturation is frequently called the *dew point.*

Hoar-frost.—If the dew point of the air be below the freezing point, the excess of vapor will be precipitated as fine spikelets of ice, which constitute *hoar-frost.* Hoar-frost is not frozen dew, but a *sublimate, i. e.*, vapor precipitated in a solid form.

Both dew and hoar-frost are precipitated most copiously upon such objects as cool fastest, and thus become the coldest. Grass, trees, and herbage generally, though no better radiators than the soil or rocks, cool faster, because, being isolated, they lose heat by radiation faster than they receive it from below by conduction.

Distribution and Amount of Precipitation.—The total amount of water precipitated upon the earth in all forms is for convenience called *rain-fall.* The amount of rain-fall received by the earth as a whole each year is about equal to the amount of water evaporated, but the amount of rain-fall received by the land is greater than the evaporation from its surface, while evaporation is greater than rain-fall on the sea surface. On the average, the land loses by evaporation about three fourths of its rain-fall,


DISTRIBUTION OF RAIN FALL
Annual Rain Fall,
more than 80 inches
between 30-80 "
" 10-30. "
less than 10 inches
ARCTIC CIRCLE
TROPIC OF CANCER
EQUATOR
TROPIC OF CAPRICORN
ANTARCTIC CIRCLE
(Unexplored)
Drawn in
Lambert's Projection.

while about one fourth drains into the ocean, thus maintaining its level against the excess of evaporation from its surface. The rain-fall *on the land* amounts to about 30,000 cubic miles of water annually,—enough to cover the whole land surface to a uniform depth of 33 inches. But all parts of the land do not receive equal quantities of rain-fall. The accompanying chart indicates the distribution of mean annual rain-fall over the land.

The reasons for the peculiar distribution will appear in the chapter on Climate, but it may be stated here (1) that the vapor taken up by the winds from the ocean is the ultimate source of rain-fall on the land; (2) that all sea winds reach the land nearly saturated with vapor; (3) that such winds in warm latitudes contain much more vapor than in cold latitudes; and (4) that the vapor in any wind is condensed into rain-fall *only by the cooling of the air.* This is usually achieved either by the *rising* of the air or by its *entrance into colder latitudes.*

Evaporation, like rain-fall, varies in different localities and in the same locality at different times. It is most active where the wind is strong and the air is relatively warm and dry, but it may cease altogether if the amount of vapor in the air is great. It is always active in any region when the wind is blowing from a colder region, or when the air is sinking, for in both cases the air is becoming warmer and its relative humidity is consequently decreasing.

CHAPTER V.

MOVEMENTS OF THE ATMOSPHERE.

The wind goeth toward the south, and turneth about unto the north; it whirleth about continually, and the wind returneth again according to his circuits.—ECCLESIASTES 1: 6.

Wind.—Sensible movements of air are called *wind.* Winds are caused by the force of gravity,—the same force that causes the flow of rivers. Gravity, however, could not produce movement in the river had not moisture, in the form of vapor, first been raised to a higher level. This is accomplished by the energy of the sun's heat. The sun's heat also enables gravity to produce winds.

Cause.—The sun makes some parts of the earth's surface warmer than others. The warmer part heats the air in contact with it. This air consequently expands. The expansion may not affect the highest layers of the atmosphere, but it pushes the lower layers up into a convexity over the warmer regions, as in Fig. 32.

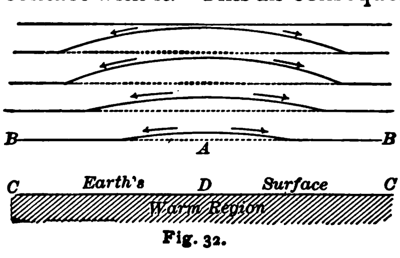


Fig. 32.

Gravity now causes the movement indicated by the arrows, for, as the result of expansion below *A*, the air above is compressed and rendered denser than that over *B*. As part of the air over *A* thus moves away, the weight or pressure on *D* tends to decrease, and to increase over *C*; but to equalize these pressures, the lower air moves as a wind toward *D*. The warm, expanded air is

lighter than the surrounding cool air, and is forced by it to rise, thus forming an ascending current over the warm region, while over the surrounding cooler region the air is gradually settling downward as the bottom air moves from under it. The general movements indicated by the arrows

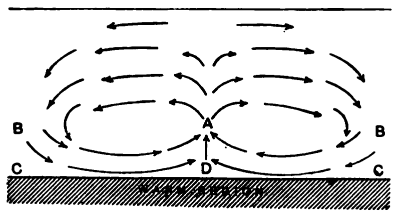


Fig. 33.

in Fig. 33, result. As the air thus rises over but one locality, while it sinks down in the entire surrounding region, it must ascend faster than it descends.

The movements continue as long as the central air is warmer than that surrounding, for so long the densities are unequal, and gravity produces movement. Thus, every wind that blows on the earth's surface has its counterpart, blowing in a different direction, at some distance above that surface. The lower wind blows toward a region of low pressure, where the air is rare and rising, and from a region of high pressure, where the air is dense and sinking.

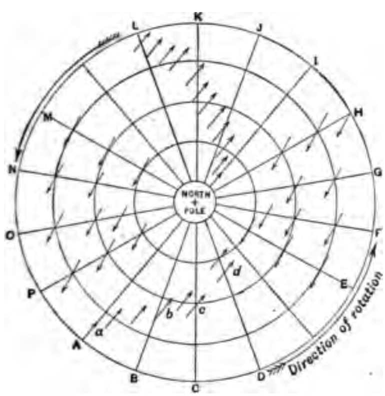


Fig. 34.

The Rotation of the Earth appears to deflect all winds from a straight course. The deflection is to the right in the northern, but to the left in the southern hemisphere.

Suppose figure 34 to represent the northern hemisphere, and a wind, shown by the arrow at *a*, to be blowing poleward along the meridian *A*. While the wind is advancing to *b*, *c*, and *d*, the rotation of the earth carries meridian *A* forward, say to the positions of *B*, *C*, and *D* re-

spectively. The change in the direction of the meridian, consequent upon its change of position, causes the direction of the wind, which was northward at *a*, to become successively more and more easterly at *b*, *c*, and *d*; and as we are apt to regard the direction of the meridian as fixed, an apparent deflection of the wind to the right is the result. The same cause produces a gradual northward deflection of a wind blowing due west over meridian *E*, as rotation carries the meridian of the wind successively to positions *F*, *G*, *H*. A wind blowing south on meridian *I* appears to turn westward, as rotation carries its meridian to positions *J*, *K*, *L*; while a wind blowing due east on *M* appears to turn southward as its meridian advances to *N*, *O*, *P*. Thus, a wind blowing in *any* direction in the northern hemisphere appears to turn to the right from its original course as it advances. In the southern hemisphere, the apparent deflection is to the left, because when we change our point of observation from the north to the south pole, the direction of the earth's rotation appears to be reversed. Figure 34 accurately illustrates the cause of the apparent deflection, but exaggerates its amount. Really there is no deflection of winds at the equator; but on leaving the equator, the amount of the deflection increases first rapidly, and then very slowly, and is greatest near the poles.

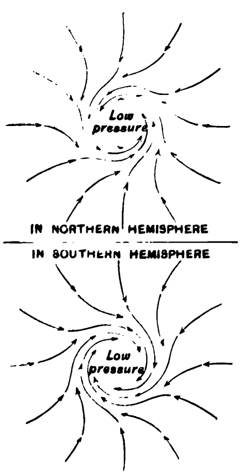


Fig. 35.

The Effect of this Deflective Tendency is to prevent the winds from moving directly toward a warm region. Starting directly toward it, the winds are deflected as they advance, and so approach the warm region obliquely; hence, when winds from all directions blow toward some central area, the deflective influence causes them to form a spiral whirl around the central area. The direction of the whirl is obviously to the left of an observer at its center in the northern hemisphere, but to the right in the southern hemisphere.

In approaching a central point, the winds move as if confined in constantly narrowing paths, and hence blow with increasing violence as they advance. This is because the air that crosses the broader portion of the path, near the margin of the whirl, must cross the narrow portion, near its center, in equal times, in order to make room for the following air.

Pressure in the Whirl.—When water has a rapid rotary motion, as in an eddy, its surface is observed to be depressed near the center and elevated near the circumference of the whirl. This is caused by the centrifugal force developed by its rotary motion. The same force is developed by the rotary motion of air, and causes a *decrease of atmospheric pressure* in the center of a whirl, from which the pressure increases gradually to its circumference.

The lowest layer of air, being greatly impeded by friction on the earth's surface, does not rotate so fast as the next higher layer, and each layer, being less dense, offers less frictional resistance to the stratum above; hence, the upper strata develop great centrifugal force and a large central area of depression, while the lower strata develop less centrifugal force and a small area of depression. The lower winds, pushed by the greater pressure behind, flow spirally toward the central area, where they slowly ascend; they move fastest near the center, and as they flow spirally outward aloft, their velocity decreases.

Three Classes of Winds.—Since winds are caused by inequalities in the weight or density of the atmosphere in adjacent regions, and since these inequalities of weight are caused primarily by differences of temperature, winds may be divided into *three classes* according to the permanence of their exciting cause: (1) As equatorial regions are *always* warmer than polar regions, there must be winds constantly blowing toward the equator in the lower atmosphere, and from the equator in the higher atmosphere. These may be called *Constant* winds. (2) As the land and water surfaces have different temperatures, the

land being generally warmer in summer, and the water in winter, there must be winds blowing, in the lower atmosphere, toward the land during one part of the year, and from the land during another part of the year. These may be called *Periodic* winds. (3) The whole of a land or water surface is seldom equally heated; some places are hotter than others, owing to local or temporary causes. There are, therefore, temporary winds blowing in the lower atmosphere toward these warmer places from all surrounding regions. These may be called *Occasional* winds.

Constant Winds.—The high temperature near the equator creates a belt of expanded and rising air, toward which surface winds blow from the northern and southern hemispheres, and from which the upper winds move over either hemisphere. The movements cause a belt of low pressure along the thermal equator, and since the upper winds, moving from the equator, are advancing from all directions toward a common center (the pole), they gradually form an immense whirl, which in turn causes an area of low pressure near either pole.

Tropical Belts of High Pressure.—Between the equatorial belt of low pressure, caused primarily by heat, and the polar low pressure, caused directly by the whirl of the winds, there must be, in either hemisphere, a belt of relatively high pressure. The mean position of this belt is in the neighborhood of that parallel which divides the surface of either polar hemisphere into two equal parts—the parallel of 30° N. or S. latitude. It has been seen that the lower air is pushed out in all directions from under an area of high pressure toward areas of lower pressure. Consequently, surface winds issue from the tropical belts of high pressure toward the equatorial low pressure belt on one side, and toward the areas of polar low pressure on the other side.

The Trade Winds.—On the equatorial side the winds advance readily, being urged forward by the high pressure into regions where the air is warmer and lighter. Consequently, they blow with great steadiness throughout the year. They are gradually deflected to the westward by the earth's rotation, and, since winds are named by the direction *from* which they blow, they become north-east winds on the northern and south-east winds on the southern side of the thermal equator. Their uniformity in force and direction won for them the name *trade winds*, because, like trade, they follow a fixed or *trodden* path. Their mean velocity is about 6½ miles an hour.

The Antitrade Winds.—The surface winds which issue from the polar sides of the tropical belts of high pressure, are urged forward by that pressure into regions where the air cools and becomes heavier. This frequently impedes the advance of the air, and consequently the winds are not so constant as the trade winds. By the earth's rotation they become south-west winds in the northern, and north-west winds in the southern hemisphere; and since these directions are opposite to those of the trade winds, these winds are called the *antitrade winds*. Since these winds form part of the great polar whirl, their velocity increases as they approach the center of the whirl (page 81). Their mean velocity on the Atlantic in 50° latitude is about 30 miles an hour.

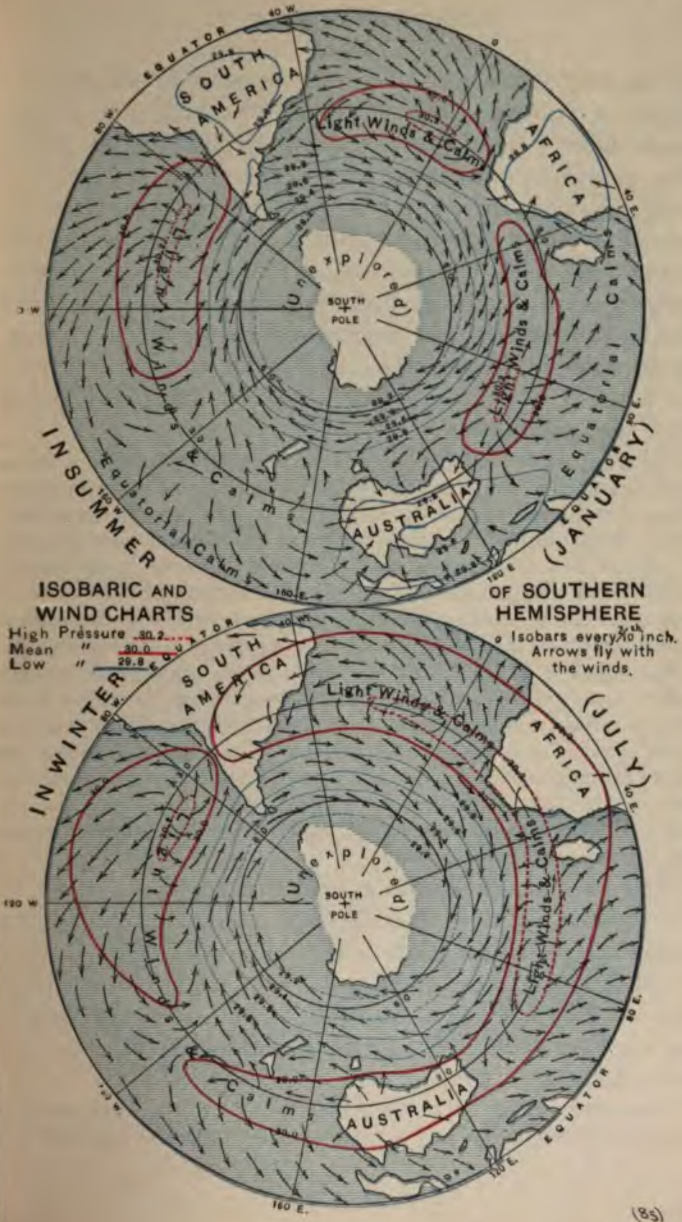
Belts of Calms.—In the belt of low pressure near the thermal equator, where the motion of the air is upward, and in the tropical belts of high pressure where the motion of the air is downward, the movement is largely insensible, and calms or light, variable winds are the result. These calm belts travel northward and southward as the sun becomes vertical over different latitudes in different seasons of the year. In the Pacific, the equatorial calms

extend south of the equator in January, but lie entirely north of it in July; while over the greater part of the Atlantic they are north of the equator during the entire year—about 2° north in January, and about 10° north in July. The trade and antitrade winds and the belts of calms are better defined on the ocean than on the continents, because the sea surface has a more uniform temperature, and because that surface is smoother than the land and offers less frictional resistance to the winds.

The constant winds are more plainly marked in the southern hemisphere than in the northern hemisphere, because there is but little land in the south temperate zone to become in turn hotter and colder than the surrounding ocean as the seasons change, and thus to modify the direction of the winds. Therefore, the Wind Charts of the Southern Hemisphere, on the opposite page, are given first. On these is shown the direction of the prevailing winds in summer (January) and in winter (July). Isobars, or lines drawn through places where the atmospheric pressure is the same, are also shown, the isobars denoting the mean or a high pressure (30 inches or over) being drawn in red, while isobars of low pressure (less than 30 inches) are drawn in blue. It is seen that a belt of high pressure lies over each of the oceans in about 30° latitude in January, while in July this belt of high pressure almost encircles the hemisphere in this latitude. The winds blow obliquely out from these regions of high pressure, forming the trade winds on the equatorial side, and the antitrade winds on the polar side.

Periodic Winds.—In the neighborhood of the continents the direction of the trade and antitrade winds is constantly undergoing a gradual change, owing to the seasonal variation in the relative temperature of the land and water; hence, in such regions the constant winds become periodic winds. There are two kinds of periodic winds: *seasonal* winds and *diurnal* winds.

Monsoons.—Most of the land on the globe lies in the north temperate zone. In these latitudes, it has been seen, the land is warmer than the adjacent ocean in summer, but colder than the ocean in winter. In summer, therefore,


IN SUMMER (JANUARY)
ISOBARIC AND WIND CHARTS OF SOUTHERN HEMISPHERE
High Pressure 30.2
Mean " 30.0
Low " 29.8
Isobars every 1/10th inch.
Arrows fly with the winds.
IN WINTER (JULY)
SOUTH AMERICA
AFRICA
AUSTRALIA
SOUTH POLE
Unexplored
Light Winds & Calms
Equatorial Calms
Calms
EQUATOR

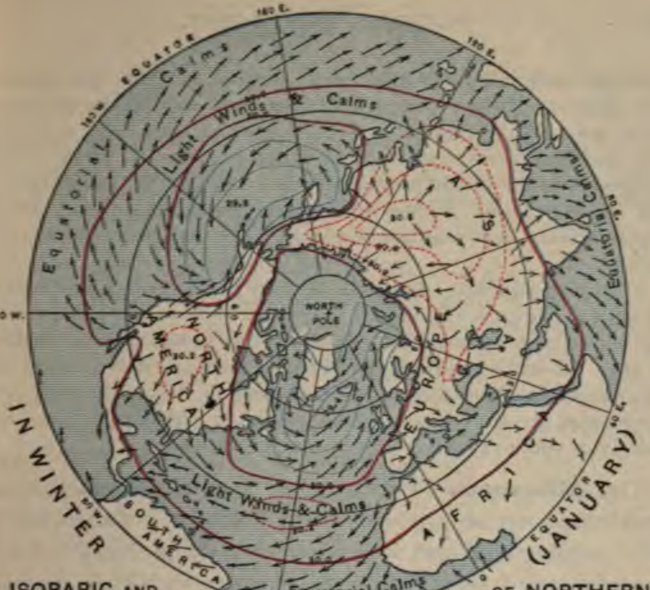
the air over the land is the more expanded, and forms a region of relatively light air, toward which the surface winds blow from the surrounding oceans, and in which they escape by ascending to the upper atmosphere.

In winter, on the contrary, the warmer oceanic air is the more expanded, and the colder land air is relatively dry and dense. The surface winds at this season consequently blow outward in all directions toward the ocean from the land region of greatest density where the air is sinking. These winds, blowing toward the land in summer and from the land in winter, are called *monsoons*, from an Arabic word meaning *season*.

Since uniformity of temperature is more disturbed by a large land surface than by a small one, the monsoons of continents are stronger and steadier than those of islands, and those of large continents than those of small continents. Since vapor obstructs the passage of heat rays, and since the amount of vapor in the atmosphere decreases upward very rapidly, the surface of *high land* is heated in summer, and is cooled (by radiation) in winter much more readily than low land with its moister atmosphere. Hence, a continent composed of highlands will have much stronger monsoons than a low continent. The great influence of the extensive land masses in the north temperate zone in modifying the direction of the winds in their neighborhood at different seasons is well shown on the Wind Charts of the Northern Hemisphere. Thus, in southern and eastern Asia, and over the eastern and western portions of North America, the direction of the winds in January is almost opposite to that prevailing in July.

The Monsoons of Asia and Australia.—Owing to the peculiar position of Asia with relation to the Indian Ocean, to its vast extent, and to the occurrence in that grand division of the most extensive region of very high land on the globe (the plateau of Thibet), the monsoons of the northern Indian Ocean and the Malay Archipelago are particularly well marked.

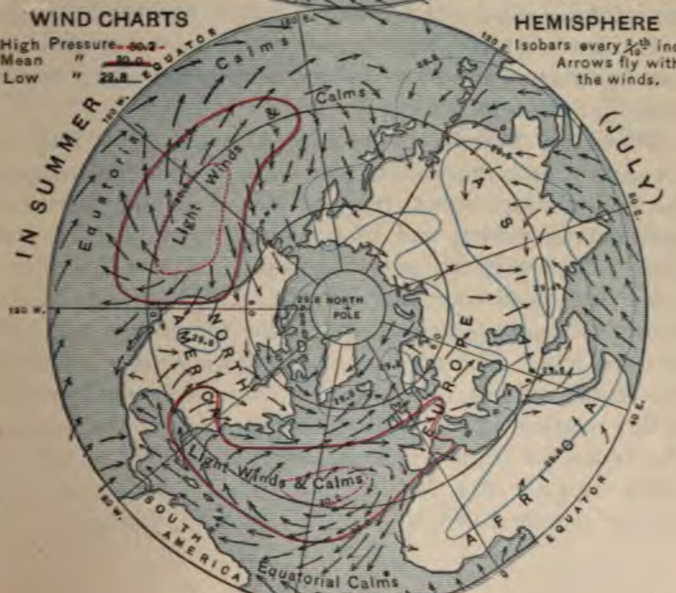
In summer, the heat upon the Asiatic highlands is greater, and the air is less dense than that on the equatorial Indian Ocean, and the



ISOBARIC AND WIND CHARTS OF NORTHERN HEMISPHERE

High Pressure 30.2
Mean " 30.0
Low " 29.8

Isobars every $\frac{2}{10}$th inch.
Arrows fly with the winds.



southern trade winds of that ocean sweep north of the equator. Here, influenced by the earth's rotation, they veer to the right and reach the coast of Arabia and India as the south-west monsoon. This monsoon blows steadily from May to October. Southerly and easterly monsoon winds prevail at this season on the south-east and east coasts of Asia, northerly winds in the northern part of the grand division, and north-westerly and westerly winds blow over Europe.

In winter, all this is changed. At that season Asia is colder than the adjacent oceans, and the air over it becomes very dry and dense. The winds blowing from this region of very dense air from October to May are influenced by the earth's rotation, and become the steady north-east monsoon of the north Indian Ocean, the north-west monsoon of the east coasts of Asia, southerly winds in Siberia, and easterly or south-easterly winds in eastern Europe.

The Monsoons of the other Grand Divisions are similar but not so pronounced as those of Asia, owing to their smaller size and lower surface. The North American regions of low pressure in summer and high pressure in winter are quite perceptible, however, and the latter, in connection with the high pressure existing over Asia at that season, has a marked influence upon the winter winds of the intervening oceans.

Effect on Winds of North Atlantic and Pacific oceans.—Since the eastern and western continents nearly touch at Bering Strait, the very dense air lying over the continents in winter, and that composing the belt of permanent high pressure over the tropical oceans, quite surround the northern parts of the Atlantic and Pacific respectively, over each of which the air is rare and the pressure low. The surface winds flowing from all sides into these regions of lighter air, are deflected by the earth's rotation into a great whirl over each of the oceans. The center of these whirls is near the parallel of 60°, in which latitude the difference between continental and oceanic temperatures is greatest (page 87, January).

Diurnal Winds of Coasts.—Near the coast the land air has nearly the same mean temperature as the adjacent sea air; but since it rests on a land surface, the air becomes slightly warmer during the day and slightly cooler at night than the sea air. A *sea breeze* consequently springs up during the forenoon and blows inland until night-fall, when, after a short calm, a *land breeze* begins to blow toward the sea, and continues until morning. On tropical coasts, these breezes occur regularly throughout the year; in higher latitudes they are not noticeable in winter, the land air being so chilled by radiation during the long nights of that season that it fails to attain the temperature of the sea air during the short days.

Diurnal Winds of Mountain Valleys.—Since the earth's surface is quickly heated by the sun's rays by day, and quickly cooled by radiation at night, and since this relatively hot or cold surface largely governs the temperature of the air resting upon it, it follows that the air resting on highlands may become hotter by day than the air at the *same altitude over adjacent valleys or lowlands.* When thus heated and expanded, the highland air flows off above and increases the pressure in the valleys. The increase of pressure drives surface winds *up the valleys by day.* At night the highland ground and the air resting on it may become cooler than the air at the same altitude over the lowland. It contracts in coöling, and upper currents begin to move toward it, thus tending to increase the pressure on the highland, and drive surface winds *down the valleys by night.*

CHAPTER VI.

MOVEMENTS OF THE ATMOSPHERE—*Continued.*

Occasional Winds include all winds which are usually called *storms*. They also include many winds which are similar to storm winds, but are not so violent. They may occur in any latitude, but are very much more frequent between the parallels of 40° and 70° than they are in other latitudes.

Whirling Motion.—Since occasional winds are directly caused by the difference in density between a comparatively small central region where the density is relatively slight, and the surrounding regions, where the density is relatively great, the air of the surrounding regions, in moving toward the central region, gradually acquires a whirling or rotary motion, which is characteristic of all occasional winds.

The whirl may begin as a comparatively small affair, sometimes but a few miles in diameter; but by the decrease of pressure in the central area, owing to the centrifugal force of the rotating winds, the diameter of the whirl may increase to 2,000 miles. The force of the winds which constitute the whirl gradually increases from the margin toward the center of the whirl. Thus, it may be a gentle breeze near the margin, and be blowing with the hurricane force of 100 miles or more an hour near the center.

Progressive Movement.—In addition to the whirling motion, occasional winds have also a progressive movement; that is, the center of the whirl, instead of remaining stationary, moves from place to place. Neither the direction nor the speed of this motion is regular, but it is

RELATIVE STORM FREQUENCY AND STORM PATHS.

The pink tint indicates regions of greatest frequency. The arrows indicate observed storm paths.

(16)

generally in nearly the direction of the prevailing wind in which the whirl occurs. The general movement is *westward and away from the equator* in the torrid zone, but *eastward and away from the equator* in the temperate zones. The average speed is from 8 to 14 miles an hour in the torrid zone, but from 17 to 28 miles an hour in higher latitudes.

These Moving Whirls constitute occasional winds. The direction of the wind at any place depends upon the position of the center of the whirl with relation to the place at the time. Thus, suppose *A* and *B* (Fig. 36) to be two places 500 or more miles apart, but both lying in the anti-trade wind region of the northern hemisphere. Let the long arrow, represented as flying north of east, indicate the general direction of the antitrade wind, and the direction in which a great whirl, represented by the small arrows, is progressing. It will be seen that, as the whirl passes, the wind at *A* is first south-east, then east, and finally north-east; while at *B* the wind is first south-west, then west, and finally north-west. Occasional winds may be broadly divided into three classes: (1) *dust whirlwinds*, (2) *cyclones*, and (3) *tornadoes*.

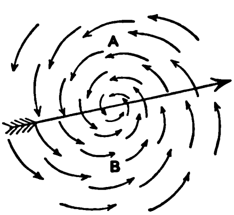


Fig. 36.

Dust Whirlwinds are essentially the draining away, upward, of a thin layer of calm, dry air, which has become excessively heated by contact with the sun-warmed earth. As sunshine is required to heat the earth, these winds occur only in the day-time. Once formed, they continue until the layer of heated air has drained away or been cooled by contact with the cooling earth after sunset. As vegetation affords a protection against the sun's

heat, dust whirlwinds are most frequent over deserts or hot turnpike roads. Although strong enough to carry along dust, sand, straw, and leaves, these whirlwinds seldom attain a disastrous force because of their short duration and consequent small diameter, and also because of the friction with the earth's surface of the thin stratum of air in motion.

In the intensely hot and sandy deserts of tropical regions, as well as in Arizona and other parts of the West, these whirlwinds attain their greatest development. In Africa and Arabia they are known as *simooms*, and are dreaded not only for the heat of the wind, but for the immense clouds of sand with which they fill the air.

Cyclones differ essentially from dust whirlwinds in being composed of moist instead of dry air. Several important peculiarities result from this difference. Moist air is heated directly by the sun's rays in the day-time, and its cooling is retarded by the radiation from the earth at night; hence, if the air is calm, heat may accumulate, and a much thicker layer of air may become excessively warm before it begins to drain upward than in the case of the dust whirlwind. When movement begins, where the air is most expanded and moist, the air cools as it ascends, and a part of its vapor condenses into clouds; hence, rain generally accompanies a cyclone. The condensation of the vapor liberates latent heat, which prevents the ascending moist air from cooling rapidly. From all these causes it results that a cyclone is not a mere daytime whirl like the dust whirlwind. It generally continues for several days, and may grow from the effects of centrifugal force, so as to involve in the whirl all the air within 1,000 miles or more of the center.

A cyclone generally continues and increases in size until the air, ascending in the central column, is no longer able to flow off above, beyond the outer margin of the

move into regions where they become colder, and in consequence of this much of the vapor is condensed. The greater amount of latent heat thus liberated on the eastern side of a cyclone is one of the prime causes of its progressive eastward movement in the temperate zones.

Anticyclones.—Many cyclones exist simultaneously in the temperate regions. They follow each other in rapid succession. One may overtake another, and they may coalesce into but one larger cyclone; or, owing to local peculiarities of heat and moisture, a large cyclone may divide into two, which diverge and pursue slightly different courses. The region between the margins of adjacent cyclones is of course a region of relatively high pressure, and is called an anticyclone, because it differs in almost every respect from a cyclone. Thus, (*a*) being a region of relatively high pressure, the surface winds blow in all directions out from it (Fig. 37) instead of into it; (*b*) these winds are deflected by the earth's rotation into outward moving spirals, the whirl being to the right of an observer at the center, in the northern hemisphere, and to the left in the southern, and consequently in a contrary direction to the movement in a cyclone; and (*c*) as the air descends in regions of relatively high pressure it becomes warmer, and therefore its vapor does not condense; hence, anticyclonic winds do not usually bring cloudy or rainy weather. Traveling to regions of greater differences of pressure, these winds move faster as they advance.

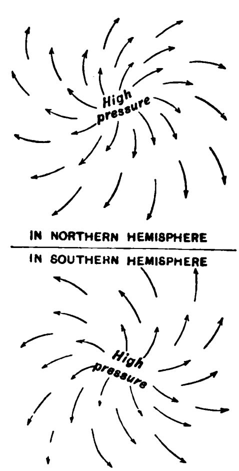


Fig. 37.—Anticyclones.

Tornadoes.—A tornado is a whirl of small diameter, but great depth and velocity, which forms a short distance above the earth's surface, and into which the surface air is "sucked up" with excessive violence. It is believed that tornadoes constitute a small secondary whirl within some gently moving cyclone. They have been known to form at all hours and in all seasons, but they occur most frequently during sultry afternoons of summer. They are

Fig. 38.—A Tornado.

supposed to be directly caused by a warm, moist current of air at some distance above the earth's surface, but underneath a higher current of cold, dry air. The moisture in the warm layer accumulates heat directly from the sun's rays and by the radiation from the earth, and becomes excessively hot in comparison with the air above. The secondary whirl, or tornado, forms about some point where the thick layer of hot air begins to escape upward, and rotates in the same direction as the cyclone in which it is formed. As the moist air ascends, expands, and

cools, the vapor condenses and forms the gyrating, funnel-shaped cloud, hanging small end downward, which serves as a warning of the tornado's approach. The funnel is formed some distance above the earth's surface, in the air; and as friction is there very slight, the winds of the whirl attain enormous speed, and develop great centrifugal force, which causes a decided decrease of pressure in the funnel. The surface air being thus suddenly relieved of a great portion of the weight of the air above, expands, often with explosive violence, and rushes with great rapidity up the funnel. Violent surface winds rush in from all sides to take its place and follow it upward. These surface winds constitute the destructive blast of the tornado.

The force of the tornado blast is terrific; it blows down the strongest houses and largest trees, and carries such heavy objects as carts, iron chains, beams, and even men and women whirling aloft in the gyrating funnel. To produce such results, a wind velocity of over 200 miles an hour is thought to be necessary. The tornado winds, however, seldom attain destructive violence over a track exceeding one fourth mile wide. Like the cyclone, a tornado has a progressive motion, usually in the direction of the prevailing winds of the region where it occurs. In the United States, tornadoes usually travel north-east at a speed of about 30 miles an hour. The tornado continues until the layer of hot air has drained away; this usually takes about an hour; hence, the track of a tornado is usually about thirty miles long.

Thunder-storms with rain and hail usually accompany tornadoes. The vapor of the ascending and expanding air in the funnel is condensed into water, which, carried upward by the powerful updraught, is converted into hail. The friction of the rapidly ascending air and water particles possibly generates the electricity manifested in the thunder-storms.

Cloud Bursts.—The ascent of air in a tornado may be so violent as to prevent the fall of rain-drops, and thus cause an enormous accumulation of water in the air.


RELATIVE
TORNADO FREQUENCY
IN THE UNITED STATES
Since A.D. 1794
1 or more tornadoes
15 " "
30 " "
50 " "
DOMINION OF CANADA
ONTARIO
WASHINGTON
OREGON
IDAHO
MONTANA
WYOMING
N. DAKOTA
S. DAKOTA
NEBRASKA
MINNESOTA
IOWA
WISCONSIN
ILLINOIS
INDIANA
OHIO
PENNSYLVANIA
NEW YORK
MAINE
MASS.
CONN.
NEVADA
UTAH
COLORADO
KANSAS
MISSOURI
KENTUCKY
TENNESSEE
N. CAROLINA
SOUTH CAROLINA
CALIFORNIA
ARIZONA
NEW MEXICO
ARKANSAS
MISS.
ALABAMA
GEORGIA
TEXAS
LOUISIANA
FLORIDA
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
MEXICO
LOWER CALIFORNIA
BAHAMA

Upon the cessation of the updraught, the water may fall in continuous streams. This is called a *cloud-burst*. Each of these streams may excavate a great hole, or basin, in the ground, and on steep slopes may occasion a land-slide or a great ravine, and wash large rocks and trees bodily down the hillside. Such a cloud burst occurred at Springfield, Ohio, in May of 1886, and occasioned great damage, inundating dwellings, and washing away railroad embankments.

Water-spouts and White Squalls.—When a tornado occurs at sea, and its funnel-shaped cloud descends to the surface of the water, the violently agitated water is sucked up for a short distance into the funnel; but at a height of a few feet it breaks into spray, which is carried aloft by the whirling winds, thus presenting the appearance of a solid, whirling column of water, or *water-spout*. *White squalls* are simply small, fair weather tornadoes. They frequently cause water-spouts, and may be quite violent.

Frequency of Tornadoes.—During the twelve years prior to 1883, over 500 tornadoes occurred in the United States, or an average of one every nine days. They occur in Kansas, Illinois, and Missouri more frequently than elsewhere in the Union. In this region the warm southerly surface winds of summer, underrunning the colder westerly winds in the upper atmosphere which have crossed over the Rocky Mountains, afford conditions peculiarly favorable for tornado formation. The accompanying chart shows the relative tornado frequency in different parts of the United States. The deeper shading shows regions where tornadoes are more frequent.

CHAPTER VII.

LUMINOUS PHENOMENA OF THE ATMOSPHERE.

By what way is the light parted?—JOB XXXVIII: 24.

Apparent Displacement of Heavenly Bodies by Refraction.—The sun, moon, and other heavenly bodies are visible when they are really below the horizon, owing to the refraction (page 26) of their rays as they penetrate the increasingly denser atmosphere in approaching the earth's surface. In the torrid and temperate zones the sun thus appears to rise in the morning earlier and set in the evening later than it really does by from 2 to 27 minutes, according to the latitude of the observer and the season of the year.

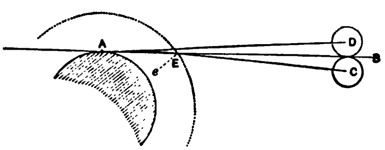


Fig. 39.

If *AB* represent the horizon line of an observer at *A*, a ray from the center of the sun or moon, *C*, entering the atmosphere at *E*, is refracted into a curve as it traverses successively denser layers of air. The observer at *A* sees the sun in the direction in which the ray is traveling at the instant it enters his eye, or at *D*. The amount of this displacement decreases from about the apparent width of the sun, at the horizon, to nothing at the zenith, where the rays fall with no obliquity. This explains the oval shape sometimes observed in the sun or moon when near the horizon; for the lower edge, whose rays strike the atmosphere more obliquely, is displaced more than the upper side.

The Sun and Moon appear larger near the Horizon than when higher in the sky. They are, of course,

not really any larger or nearer at such times, and the appearance has nothing to do with refraction, but arises simply from a common error of judgment on the part of the observer.

All objects appear smaller as their distance increases, and our only means of judging the size of a distant object whose dimensions are unknown, is by comparing it with the apparent size of some equally distant but familiar object—as a man, a tree, a house, etc. When low in the sky, the sun or moon is in a position where it may be directly compared with familiar objects on the distant horizon, and its great relative size impresses itself upon us and makes it seem actually larger than when seen higher in the heavens with no standard of comparison near it. For the same reason we are apt to think that a full grown man at the top of a steeple 200 feet high is only a boy. No one makes such a mistake with regard to a man at the same distance when he is surrounded by familiar objects on the earth's surface which serve as standards for comparison.

Twilight.—After the sun has disappeared below the horizon, the earth is not immediately plunged into darkness: objects remain visible by the light reflected from the higher parts of the atmosphere which is still traversed by sunbeams. This is called *twilight* (half light). The same phenomenon occurs before sunrise, and is called *dawn*.

Even when the sun is in the zenith of a cloudless sky, as much as one fifth of the light we receive is that which is reflected to us from other quarters of the sky than that through which the beams penetrate directly to us. When the sun is just above the horizon, more than two thirds of our light is that which is reflected from the sky; and when it is invisible below the horizon, all our light is so reflected to us. Suppose the ray *SE* (Fig. 40) is the last from the setting sun which strikes *A*. *A* is illuminated by this direct ray, and by rays reflected from every point of the sky from *H* to *F* which is still traversed by the sun's beams. The sun's rays can not reach *A* when rotation has carried it to *C*, and lifted its horizon

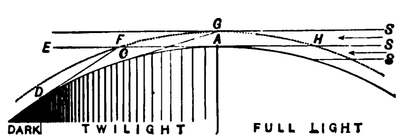


Fig. 40.

to *G;* but *C* is not dark because reflected light from every point of the sky between *F* and *G* reaches and illuminates it with twilight. When the horizon is lifted to *F*, however, by the earth's rotation to *D*, neither direct nor reflected light from the sun reaches that part of the earth's surface, and darkness prevails.

"The Sun drawing up Water."—When a ray of light is admitted into a dark room, its path becomes visible by the light reflected from the air particles and floating dust motes (page 27). The same phenomenon on a grand scale is sometimes seen in the open air when the sunbeams, breaking through rifts in the clouds, are rendered visible in the clouds' shadow by the light reflected to the eye from the strongly illuminated dust and air particles in their path. This phenomenon is frequently but erroneously supposed to be "the sun drawing up water."

Mirage.—Adjacent layers of air near the earth's surface have sometimes, owing to differences in temperature or humidity, widely different densities. The refraction and total reflection of light rays in traversing such layers often give rise to distorted, displaced, or inverted images of the objects from which they proceed. This phenomenon is called *mirage*. The suitable atmospheric conditions may occur in any region, but are probably most frequent over hot deserts. Looming and Fata Morgana are but peculiar instances of mirage.

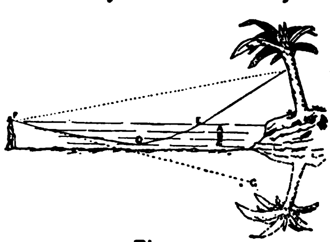


Fig. 41.

Suppose the heated ground has warmed the lower layers of the atmosphere, *A*, *B*, *C* (Fig. 41), to a much higher temperature, and thereby made it much rarer than the air above. The rays indicated by the dotted line reveal the tree to the observer at *F* in its proper position, but the ray striking the layer of rare air at *E* is refracted more and more as it enters rarer layers, until it strikes a layer so obliquely as to be totally re-

flected at *D*. The observer sees an inverted tree in the direction *G* at which this ray enters his eye, and the impression conveyed is that the real tree is standing on the bank of a lake, in which its inverted reflection is seen. The cold surface of the sea may sometimes so chill and render relatively dense the lower layers of the atmosphere, that rays passing from a vessel at *A* (Fig. 42), completely hidden from the observer at *C* by the rotundity of the earth, are refracted downward by the rarer layers of the higher atmosphere, and totally reflected at *B*, thus producing an image of the concealed vessel in the clouds at *D*, above its true position, and in the direction which the ray entered the observer's eye. The image may sometimes be erect, sometimes inverted, and may be greatly enlarged. An image of a vessel 30 miles distant from the observer has thus been seen, and the image of the French coast, which is usually invisible, has thus been lifted into the view of those on the opposite side of the English Channel. Lateral displacement occurs when the layers of air of different density are vertical, or more or less inclined to the horizontal.

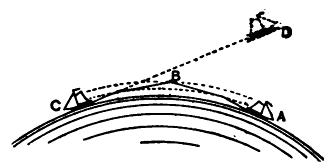


Fig. 42.

Color of the Atmosphere.—In small masses, air has no appreciable color. In large masses its color varies with its position in relation to the sun. If the sunlight passes directly through the air to the eye, we see the air by *transmitted* light, and it is reddish if the sun is near the horizon, but yellowish if the sun is high in the heavens. If the air we observe is not directly between the eye and the sun, we see it by the sunlight which it *reflects* to the eye, and it appears azure, or bluish. It is the color of the atmosphere, thus seen, which makes the sky and distant hills or mountains appear blue.

It has been seen (page 28), that a colorless ray of sunlight, passing through a prism, is refracted and separated into a number of colored rays. The only difference in these colored rays is thought to be the width of the ether waves, or vibrations, which are supposed to constitute all light; the blue is conceived to be caused by short, quick waves, and the red by longer and slower

waves, while the original colorless ray is supposed to be composed of waves of all lengths, unassorted. Now, the atmosphere is known to contain myriads of floating dust motes and other particles, which vary in size from an inconceivable smallness to the size where they can no longer float, but fall through the air to the earth's surface. If an ordinary water wave encounter a *small* chip or other floating object, it simply passes under the object and continues its course. If, however, it encounters a much *larger* object, the wave is unable to lift it, and, striking against it, breaks and rebounds, that is, *is reflected* from it. The floating dust motes have much the same effect on the light waves passing through the atmosphere. The shorter blue waves are broken and reflected not only by the larger motes, but by those which are too small to reflect the longer yellow and still longer red waves. Thus, when a ray of sunlight passes through the atmosphere, more of its blue waves than of its yellow and red waves are reflected to the eye, and hence objects seen by such *reflected* sunlight, in which the short blue vibrations predominate, appear more or less bluish. When, however, a ray of sunlight passes directly through the atmosphere to the eye, more of its blue waves have been reflected into other directions, and the reddish and yellowish waves are in excess in the *transmitted* light. When the sun is near the horizon, its rays pass through great distances of the lower atmosphere, which contains the largest motes, and the yellow as well as the blue waves are sifted out by this process of *selective absorption* of the atmosphere (page 28), leaving the transmitted light reddish. The remarkably long and brilliantly red sunsets and twilights of the fall and winter of 1883-4 are thought to have been caused by the ordinary action of this selective absorption. They were remarkable, however, because the amount of dust in the higher atmosphere was unusually large at that time, great quantities having been gradually diffused over the entire globe from the terrific volcanic eruption of August, 1883—at Krakatoa, in the Strait of Sunda, between Sumatra and Java (page 285).

Color of Clouds and Snow.—Masses of cloud and snow are nearly opaque, although composed of minute particles of transparent water or ice; for while most of the light falling upon each particle is transmitted through it, and but little reflected from it, still there are so many particles, and hence so many minute reflections, that all the light is reflected away from the eye before it can traverse

the mass of cloud or snow. When seen by directly reflected sunlight, and not too distant, the sensation appropriate to colorless opaque bodies is excited, and the cloud or snow appears milk white; but clouds, if very distant and high above the horizon, appear bluish, while distant snow or clouds near the horizon appear yellow or red, because the dense atmosphere reflects the blue waves of their rays away from the eye.

The Rainbow is the beautiful arc, containing all the colors of the spectrum, which is usually seen through a shower or heavy mist, upon which the sun shines from a point behind the observer. It is caused by the separation of white sunlight into its prismatic colors by refraction in the water drops, and the total reflection of these colored rays back to the eye of the observer. Each color and each point in the arc is the instantaneous reflection from a separate drop. The exterior edge of the rainbow is red, and the interior edge is blue or violet. Sometimes a double arc or rainbow is seen, in which case the outer one is wider but fainter than the inner one, and the order of its colors is reversed.

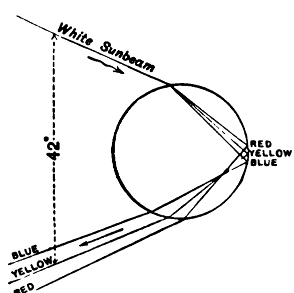


Fig. 43.

When a beam of sunlight enters a drop of clear water at a certain angle, it is totally reflected from the interior surface, and emerges on the same side of the drop at which it entered. In addition to this, while the beam is traversing the drop, refraction separates it into its colored rays, of which only the red, yellow, and blue ones are indicated in Fig. 43. If the position of this drop is such that the reflected red ray enters the eye of the observer, the other colored rays pass above the eye and the drop appears red. But at the same instant a similar phenomenon takes place in other drops at such distances below the first that only their yellow and blue rays respectively enter the eye, causing these drops to appear respectively

yellow and blue,—the lower drop appearing blue. Between these drops are others which reflect their appropriate color, and the whole series of drops gives the appearance of a continuous party-colored band, the red above gradually changing through yellow to blue below. Each drop occupies but for an instant the proper position for its reflection to enter the eye, but this position is so soon occupied by a following drop that the sensation is continuous. The angle between the sunbeams and the reflected rays is always nearly 42°. Each part of the shower reveals prismatic colors at a point where lines drawn to the sun and the eye inclose an angle of 42°. Collectively, these points form the curve of the rainbow. The second exterior rainbow sometimes seen is caused by the refraction and two reflections of the sunbeam within the drop (Fig. 44).

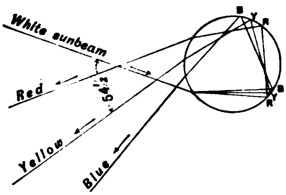


Fig. 44.

Halos and Coronas are sometimes seen around and at some distance from the sun or moon. The halos result from the refraction of light in ice crystals which compose the highest cirrus cloud, and are more or less distinctly colored. Coronas may be colorless, and are caused by the diffraction from the surface of haze- or cloud-globules. If these are small, the diameter of the corona is great, and vice versa; hence, when a ring is seen closely encircling the moon, the globules of water in the clouds are known to be large, and rain may be expected.

Atmospheric Electricity.—The atmosphere is always more or less highly charged with electricity. This is probably a result of evaporation, and the friction of air and vapor particles with each other. Millions of vapor particles condense into a single cloud-globule; hence, however small the electric charge on a single vapor particle, the accumulation in a cloud mass might be enormous.

Lightning.—When an electrified cloud approaches another cloud or the earth sufficiently close, its electricity and the opposite kind *induced* on the neighboring cloud or

the earth, rush together through the intervening air, producing the great electric spark called *lightning*. This electricity travels with the enormous velocity of radiant light and heat (186,000 miles a second). A flash of lightning, therefore, though often one mile, and sometimes more than five miles in length, seems instantaneous. There are at least three varieties of lightning: (1) *forked lightning*, (2) *sheet or heat lightning*, and (3) *ball lightning*.

Forked lightning is a sharp, zigzag line of dazzling white light, marking the line of least resistance through the dense lower air between two highly charged clouds, or a cloud and the earth. *Sheet lightning* is the most common form, and occurs as a broad sheet of rather pale, diffused light. Frequently it is not accompanied by audible thunder. Usually it is distant forked lightning, but sometimes is a weak electrical discharge within a cloud at a considerable height where the air is rare. *Ball lightning* is a very rare form. A vivid flash, accompanied by a violent explosion, seems to project a brilliant bomb to the earth. Upon striking the earth, the bomb may rebound several times before it splits up and disappears. No satisfactory explanation has been given of this singular form of electrical discharge.

Thunder is simply the crackle of the lightning spark. It has the same cause (page 34) as the much feebler crackle of the smaller sparks produced artificially. The passage of electricity is so rapid that the crackle is produced at practically the same instant throughout the length of a lightning flash several miles long. But as sound requires almost five seconds to travel one mile, it arrives from successively more distant points at sensibly later periods of time, and thus produces the continuous roar or roll of thunder. The sound is further prolonged and repeated by being reflected, or *echoed*, from the surfaces of clouds, the earth, and masses of air of unequal density. Thunder is seldom heard over a greater distance than twelve miles.

St. Elmo's Fire.—Atmospheric electricity of very low intensity, such as often occurs in fair weather, is frequently sufficient to induce in prominent, sharp-pointed objects, a greater amount of electricity than the attenuated object can hold, and what is called a *brush discharge* takes place, without audible noise, but frequently with a feebly luminous glow. This glow is often seen at the ends of lightning rods or of the masts and spars of vessels, and is called by the sailors *St. Elmo's Fire.*

The Aurora Polaris, or Polar Light, is a singular and beautiful phenomenon seen in the sky, most frequently in high latitudes, but occasionally in all parts of the earth. It consists of luminous clouds, arches, or rays. The rays frequently shoot up and down in diverging lines from the horizon, and appear to converge in the zenith. The aurora is usually a pale, greenish yellow, but sometimes is crimson, violet, or steel blue. In the northern hemisphere, the phenomenon is most common in a narrow zone surrounding, but at some distance from, the magnetic pole of the earth.

This zone embraces the Faroe Islands, and crosses central Labrador, Hudson Bay, and Point Barrow in northern Alaska, and then skirts the north coast of Asia. North of this zone the aurora is generally seen in the southern sky, but south of the zone in the northern sky. The height of the aurora varies greatly, but its average altitude seems to be about 100 miles, and hence in a region where the atmosphere is exceedingly rare. The cause of the aurora is unknown; it is certainly connected with the magnetism of the earth, and probably results from the discharge of atmospheric electricity.

PART III.—THE SEA.

CHAPTER VIII.

DEPTH, COMPOSITION, AND TEMPERATURE.

Thy way is in the sea, and thy path in the great waters.—PSALM LXXVII : 19.

The Sea is a continuous body of water which partly envelopes the earth, forming nearly three fourths ($73\frac{1}{3}\%$) of its surface.

Oceans.—The polar circles, the continents, and the meridians from their southern points are taken as the boundaries of five great divisions of the sea, called *oceans*, which vary greatly in shape and extent.

The Pacific is the largest ocean. It is oval in shape. The greatest width in an east and west direction lies along the equator, and is about 10,000 miles. Its length, from Bering Strait to the Antarctic Circle, is 9,000 miles. It embraces 71,000,000 square miles,—about one half (49%) of the total sea area.

The Atlantic Ocean is next in size. It is a long and narrow channel, extending 9,000 miles between the polar circles, with an average width of 3,600 miles. Its area is 34,000,000 square miles, or 24% of the sea surface.

The Indian Ocean is roughly circular in shape, having a diameter of about 6,300 miles, and an area of 28,000,000 square miles, or 20% of the sea surface.

The Antarctic Region, lying within the Antarctic Circle, is circular, with a diameter of 3,300 miles, and an area of 7,000,000 square miles, or 4½% of the sea surface. About 4,700,000 square miles of this region have never been explored. The unexplored region is supposed to contain a low continent or large island-group completely covered by a continuous ice cap more than 2,000 feet thick, which terminates on all sides in a perpendicular cliff of ice about 200 feet high above sea-level.

The Arctic Ocean is really a great gulf of the Atlantic, extending for 3,300 miles from Iceland to Bering Strait. It has a width of less than 2,500 miles, and an area of 4,000,000 square miles, or 2½% of the sea surface.

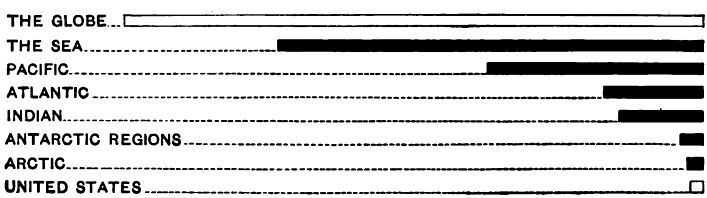


Fig. 45.—Relative Areas of the Oceans.

Continuity of the Sea.—The Pacific, Atlantic, and Indian oceans are wide and open at the south, where, together with the Antarctic, they form a continuous and uninterrupted sea as far north as Cape Horn, a point corresponding in latitude to central Labrador and Denmark in the northern hemisphere. From this sea each ocean extends northward as a great bay or channel. At the tropic of Cancer the Indian Ocean encounters Asia and ends; at the Arctic Circle the Pacific practically ends at the shallow and narrow Bering Strait, leaving the Atlantic alone to make a broad connection with the Arctic Ocean, and carry the continuity of the sea into the frozen regions about the north pole.

Atlantic Coast.—The Atlantic, and its northern extension, the Arctic Ocean, send the greatest number of deep indentations into the land. In general these indentations have comparatively narrow mouths, and form great *inland seas*. Thus, to the Atlantic and Arctic basin belong the Gulf of Mexico, Hudson Bay, the Gulf of Obi, White, Baltic, Mediterranean, and Black seas. For this reason the Atlantic, although it has but one half the area, has a longer coast-line than the Pacific. The Atlantic coast is 55,000 miles long; that of the Pacific but 47,000.

The Pacific Coast, while much more regular than that of the Atlantic, possesses the greatest number of *border seas*, partially separated from the main ocean by chains of islands. Such are Bering, Okhotsk, Japan, Yellow, and China seas, the seas of the Malay Archipelago, the Coral Sea east of Australia, and the expanses of water within the numerous islands of southern Chile, British America, and Alaska.

The Indian Ocean is peculiar in the number and size of the great open-mouthed indentations in its coast-line, such as the Gulf of Aden, the Arabian Sea, the Bay of Bengal, Timor Sea, and the Great Australian Bight.

Average Depth.—The average depth of the sea is 2,150 fathoms (1 fathom equals 6 feet) or 2½ miles. That of the Pacific is 2,500 fathoms or about 3 miles; that of the Atlantic and Indian oceans is 2,000 fathoms or 2¼ miles; and that of the polar oceans is probably less than 1,000 fathoms or about 1 mile. While these are the *average* depths, there are places where the depth is much greater, and others where it is much less. The blue shading in the charts indicates the portions of the earth's surface that would still be covered with water were the surface of the sea lowered 2,000 fathoms. The white portion of the chart indicates the region that would thus be

converted into dry land. A depression of the sea surface of 4,500 fathoms or about 5 miles, would be required to convert the whole surface of the earth into dry land.

The dotted line in the white portion of each chart indicates the shore-line of the sea were its surface lowered only 1,000 fathoms; the darker blue tinting indicates regions that would still be covered with water were the present sea surface lowered 3,000 fathoms—3½ miles—while the small areas of solid blue east of Japan and the West Indies indicate the deepest depressions of the earth which would remain sea were the present surface lowered 4,000 fathoms or 4½ miles.

Depths of the Sea Compared with Heights of the Land.—The greatest depressions of the earth are about

as far below, as the highest mountains are above the sea surface; but the area of deep depressions is very much greater than that of high elevations. Thus, about 83% of the sea area, or 114 million square miles, is more than 1,000 fathoms deep; while but 9% of the land, or about 5¾ million square miles, has an elevation greater than 1,000 fathoms (6,000 feet) above sea-level. This elevated region of the land is indicated on the chart by the darkest red tint. It is estimated that it would require all the solid portion of the planet down to a depth of 1,600 fathoms below sea-level to fill the greater depressions up to that depth.

Configuration of the Sea Bottom.—The sea bottom is much smoother than the surface of the land. It sinks more or less rapidly from the shores of the continents to its average depth, and continues as a vast, gently undulating plain to the opposite continent.

Submarine Plateaus.—Occasionally an undulation may rise gradually to an elevation a mile or two above the plain, and continue for a greater or less distance as a plateau, at a depth of 1,000 or 2,000 fathoms, before again sinking. The narrower of these plateaus or ridges correspond in a general way with the broad plateaus of the land, but it is probable that the sea bottom far from land, contains no narrow and rugged irregularities comparable with mountain chains.

The Atlantic.—A submarine plateau, or broad ridge, extends along the middle of the Atlantic throughout its length, and separates its basin into an eastern and a western depression. The average depth on this plateau is 1,500 fathoms, while the two depressions into which it divides the basin of the Atlantic sink to mean depths of over 2,500 fathoms.

The Pacific basin is more intricate than that of the Atlantic. Submarine ridges from the south polar regions towards Chile and the isthmus of Panama, and towards New Guinea, separate four depressions from the main depression. The latter is imperfectly separated, by a series of discontinuous ridges extending southeastward from Japan, into a northern and a southern basin, each of which sinks to a general depth of nearly 3,000 fathoms with considerable areas of much greater depth.

The Indian Ocean is freer from submarine plateaus than either of the other oceans, but a short one appears east of Madagascar, and another extends south from the west coast of India.

Composition of Sea-water.—Unlike rain-water, or that which is common in lakes and rivers, the water of the sea is so salt and so bitter as to be undrinkable. If 100 pounds of sea-water be placed in a clean vessel and allowed to evaporate, about 3½ pounds of solid matter

will remain after the liquid has disappeared. This solid matter, dissolved in sea-water, makes it heavier or denser than fresh water, and gives to it the peculiar taste.

The amount of solid matter, and hence the weight or density of the surface water, varies slightly in different parts of the open sea, being greatest in the trade wind regions, where evaporation is greater than the rain-fall, and least in equatorial regions where the rain-fall is in excess, and in the polar seas, where the melting ice supplies a great amount of fresh water. In partially inclosed seas or bays the amount of solid matter in solution may increase to about 4%, as in the Mediterranean and Red seas; or decrease to 2½%, as in New York Bay, or to 1¾%, as in the Black and Baltic seas, according as the evaporation and the salt water received from the ocean is greater or less than the amount of fresh water received from rain-fall and rivers. The relative density or saltness of different parts of the sea is shown in the chart on page 138.

The Solid Matter.—While the amount of solid matter varies slightly, its composition remains practically the same in all parts of the sea. Rather more than three fourths of it is chloride of sodium, or common salt. The sea thus contains in solution enough common salt to form a solid layer 126 *feet thick* over the entire globe. The remaining portion of the solid matter (other than salt) gives the peculiar bitter taste to sea-water, and consists of chloride of magnesia, Epsom salts, gypsum, and traces of nearly every known mineral, minute quantities of each being dissolved in water percolating through the rocks of the land, and carried eventually by the rivers to the sea.

The percentage of the principal solids dissolved in sea-water is as follows:

Chloride of sodium (common salt)	77.758%
Chloride of magnesia	10.878
Sulphate of magnesia (Epsom salts)	4.737
Sulphate of lime (gypsum)	3.600
Sulphate of potassium	2.465
Carbonate of lime (limestone), and all others	0.562

Gaseous Matter.—In addition to its solid or mineral ingredients, sea-water always contains, dissolved, a greater or less quantity of the atmospheric gases,—oxygen, nitrogen, and carbonic acid. Bubbles of air composed of these gases become entangled in the waves of the sea surface, and the gases are dissolved and gradually diffused to the greatest depths. The quantity of gas so dissolved amounts to from 2 % to 3% *of the volume* of the sea (equal to a layer of air 230 feet thick surrounding the earth), in the proportion of about ¼ oxygen, ¼ carbonic acid, and ½ nitrogen. The oxygen is a little more abundant in the water near the surface, and the proportion of carbonic acid increases toward the bottom. It is the oxygen thus dissolved in sea-water which enables submarine animals to live. They inhale it and exhale carbonic acid.

Cause of the Saltness of the Sea.—It is believed that the mineral ingredients of sea-water were principally derived from the mineral gases in the atmosphere, when its water vapor first condensed to form the sea, at an early period of the planet's history; and hence that sea-water has always been salty.

At that time, the earth's surface was much hotter than it is now, and great quantities of the minerals which exist as solids at the present temperatures, existed then as gaseous components of the atmosphere. Under the enormous pressure of such an atmosphere, vapor might condense into clouds and rain at temperatures now required to melt iron. Hot water dissolves a much greater quantity of most minerals than cold, and such hot rain falling through such a mineral laden atmosphere would reach the earth strongly impregnated by the mineral gases through which it had passed.

There are processes now at work, however, which, by continually adding small quantities of similar minerals, tend to gradually increase the saltness of the sea. Sea-water, in evaporating, leaves all its impurities behind. The vapor condenses and falls as nearly pure rain-water.

Part of it falls on the land, and only reaches the sea again after a long journey in some stream or river. During this journey it dissolves and carries away, in solution, minute quantities of the soils and rocks with which it comes in contact. River water, however clear, is thus never pure. Upon entering the sea, it adds its mite to the quantity of mineral matter in solution.

While there are 350 parts of mineral matter in 10,000 parts of sea-water, there are but 2 parts of mineral matter in an equal quantity of river water; and being in so small a proportion, it does not appreciably affect the taste. The solution in river water depends upon the nature of the rocks encountered. The minerals of limestone, granite, and sandstone, which constitute so large a portion of the rocks of the earth, form about three fourths, and common salt but a small part of the mineral matter in river water, while the proportions of the substances are just reversed in sea-water. The reason for this is explained on page 243.

Temperature.—In general, the surface water of the sea is the warmest. Its temperature varies from about 80° near the equator to about 30° near the poles. The temperature of the water on the sea bottom, however, is about 35° under the equator, and about 29° under the polar oceans. Thus, while there is a difference of 50° between the surface temperatures of the polar and equatorial oceans, there is a difference of only 6° between the temperatures of the water on their bottoms.

Surface Waters.—The great difference between the temperatures of polar and equatorial surface waters, results from the different heating power of the sun's rays when falling almost vertically, as near the equator, and very obliquely, as near the poles. As the sun is vertical over the tropic of Cancer in June, and over the tropic of Capricorn in December, the surface waters in either hemisphere are alternately warmer and colder, according to the season of the year. This seasonal difference of tem-

perature is very slight near the equator and near the poles, but in the oceans of the temperate zones it amounts to about 10°. Thus, in the latitude of New York, the temperature of the sea surface is between 50° and 60° in winter, and between 60° and 70° in summer.

Water Beneath the Surface.—Since water is a very poor conductor of heat, the direct influence of the solar rays is confined to a comparatively thin layer of surface water. From the surface the temperature first falls rapidly as the depth increases, then more slowly, and then with extreme slowness, either to the bottom or to a certain depth, whence it remains nearly uniform to the bottom.

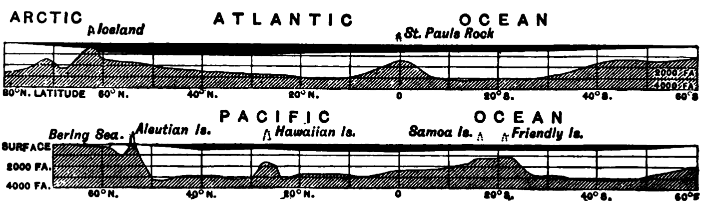


Fig. 46.

Warm and Cold Water of the Sea.—Even under the equator, a temperature of 40° is always reached within a depth of 800 fathoms, and in higher latitudes at less depths. Thus, the great mass of sea-water has a temperature below 40°, or removed but a few degrees from its freezing point. The portion of the sea which has a temperature above 40° forms a comparatively thin layer at the surface of the temperate and equatorial oceans. In the sectional diagrams, this layer is indicated by solid black.

Ice of the Sea.—Salt water freezes at a lower temperature than fresh on account of its saltness. The surface water of the sea does not begin to solidify into ice until its temperature falls below 29° Fahrenheit.

In freezing, salt water discards most of its salt, and expanding, becomes comparatively fresh ice. The discarded salt, mixing with the water immediately beneath the ice, makes it salter, and therefore it does not freeze, although as cold as the surface. It also makes it heavier, and causes it to sink and cool the deeper water, which is thus eventually cooled to about 29° entirely to the bottom.

Ice-fields and Floes.—In the frigid zones, the surface of the sea is annually frozen into vast fields of thick ice, hundreds of miles in extent. The movements of the water and variations in its temperature cause the ice to crack into immense pieces, or floes, the pressure of which, one against the other, breaks off and squeezes up huge fragments, until the whole surface of the floe becomes so rough and uneven that traveling over it is almost impossible. The portions of the ice-field near the shore are frequently covered with masses of rock and soil loosened from overhanging cliffs by the frosts of the long Arctic winter. Thousands of tons of such land rubbish are thus annually carried to sea when the ice-floe becomes detached in the early summer, and may be transported hundreds of miles before the ice melts and allows its load to sink to the bottom.

Icebergs.—Very different from the comparatively low ice-floe, both in appearance and in manner of formation, are the great *icebergs*, sometimes 200 or 300 feet high, occasionally seen floating in the Atlantic as far south as the latitude of Washington, and frequently observed stranded in the shallow waters around Newfoundland. Unlike the ice-floe, bergs are not frozen sea-water, but are land ice. They are formed of the snow, which, falling to great depths on polar lands, and accumulating in the continued cold to still greater depths, becomes consolidated under the pressure of its own weight into solid ice, which covers the greater part of the land, and increases in thickness with the accumulation on its surface, until its weight

Formation of Icebergs at Muir Glacier, Alaska.

causes it to move gradually downward as a *glacier* over the surface of the land into the sea. When it has advanced to a depth of water greater than about nine tenths of the thickness of the ice sheet, its buoyancy causes great blocks to break off and drift away as icebergs.

Observations at the foot of the Muir glacier lead Professor G. Frederick Wright to believe that most icebergs owe their detachment from the parent glacier, not to the buoyancy of the ice, but to the fact that the advance of the glacier is faster near its surface than near its bed (p. 233). Fragments of the surface ice, of greater or less volume, are thus pushed off over the submerged foot of the glacier, and these fragments float away as icebergs.

In Antarctic seas, the icebergs are usually about 175 feet high, and sometimes 3 miles long, with flat and nearly level tops. As only about one tenth of the mass of a berg protrudes above the heavy sea-water, such icebergs must extend to a depth of about 1,750 feet. As the iceberg drifts with the currents into warmer latitudes, it becomes very irregular in shape through unequal melting, and thus may turn completely over several times, and reach comparatively low latitudes before its great mass is entirely dissolved. In its journey over the land and sea bottom before it breaks away from the parent ice sheet, great masses of stone and gravel, becoming embedded in its under surface, are torn from their places and distributed over hundreds of miles of sea bottom by the gradual melting of the iceberg. The chart on page 138 shows the regions in which floating ice may be encountered.

CHAPTER IX.

WAVES AND TIDES.

Thou rulest the raging of the sea; when the waves thereof arise, thou stillest them.—PSALM LXXXIX: 9.

Movements of the Sea.—The water of the sea is in constant motion. Its movements may be broadly divided into three different classes, namely, waves, tides, and currents.

Waves.—The ordinary waves of the sea are caused directly by the impact or friction of the wind. A small local agitation of the surface water is thus produced, which spreads rapidly in all directions as a succession of undulations or waves. This phenomenon may be produced by blowing upon or along the surface of the water in a basin. Under the continued action of the wind, these waves soon grow, in the deep and open sea, into great billows. Beyond the region of the wind which caused them, the billows advance with gradually diminishing height, and may even reach the shores of the continents. As there is never a time when the winds are not blowing and creating waves in some parts of the sea, its surface, even in regions where the wind is not blowing, is almost always heaving with the "groundswell," or the diminishing undulations of waves created in some other regions.

Movement of the Water in Waves.—While the undulation advances rapidly in one direction, the water itself does not partake of this continuous progressive movement. The motion of the water is indicated by that

of a floating cork, which is observed to rise and fall as the wave passes, but otherwise to remain in nearly the same position.

In reality, the water advances while on the upper half and recedes while in the lower half of the wave, each particle moving in a nearly circular path whose diameter equals the height of the passing wave. This is illustrated in Fig. 47. A cork at *a*, on the front slope of an advancing wave, *A*, reaches *b* as the wave reaches *X*, *c* when the wave arrives at *Y*, *d* as the wave reaches *Z*, and *a* again when the wave has advanced its length to *B*. As the cork advances when above and recedes when below the medial line *ef*, and as the portion of the wave *ae* above that line is shorter than the portion *af* below, the advance of the cork, while equal in amount, is more

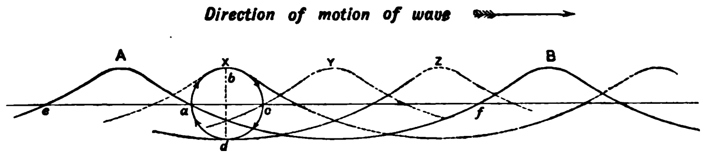


Fig. 47.

rapid than its recession. The enormous energy of waves is due to this slight but exceedingly rapid (page 17) advance of the great body of water while in the crest of the wave.

Size and Speed of Waves.—The size of waves (height from trough to crest, and length from crest to crest) in the open ocean depends upon the force and continuance of the wind. The speed increases with the size. The largest wind waves are about 50 feet high and half a mile long, and travel at the rate of 80 miles an hour. The ordinary storm waves are not more than 30 feet high and 600 feet long. They travel about 37 miles an hour.

Depth of Water Affected by Waves.—In the waves of the open sea, all motion is confined to a comparatively thin layer of surface water. At a depth equal to the wave length, the motion is less than $\frac{1}{500}$th part of that at the surface. Thus, the largest waves of the sea, which

attain a height of 50 feet, cause a corresponding movement of but one inch at a depth of half a mile (440 fathoms), while the motion of smaller waves becomes insensible long before a depth equal to their length is reached. The motion arising from the ordinary waves of the sea is probably quite insensible at a greater depth than 100 feet (17 fathoms).

Breakers.—When waves from the deep open sea reach water so shallow that perceptible wave motion reaches to the bottom, the increased friction retards the bottom of the advancing wave, and those following begin gradually to overtake it. The waves thus become shorter and higher, and their slopes, especially the front slope, become steeper as the water becomes shallower. Finally, the front slope of the wave in the shallowest water becomes so steep that the water in its crest falls forward in a graceful curve, and dashes upon the beach, amidst foam and spray, as a *breaker.*

Small waves, caused directly by the wind, break thus where the depth of water below the trough has decreased to about one half the height of the wave. The larger undulations of the ground-swell, however, sometimes break when the depth below the trough is twice the height of the wave. Waves may thus break far from the shore if the water is sufficiently shallow. "White-caps," seen on the crests of waves in deep water when a brisk wind is blowing, are simply the curling over and lashing into foam of the surface water by the wind, when exposed to its full force at the highest part of the wave.

The Force of Waves.—The force with which waves break against the shore depends upon their size, which in turn depends upon the force and direction of the wind and the extent of its contact with the water surface. Thus, the waves are stronger when the wind blows toward a coast than when it blows seaward. They are stronger upon a coast facing the open sea, than upon one protected

by outlying capes or islands. As the prevailing winds in the temperate zones are toward the east, it is generally true that in those zones the eastern shores of the oceans have the heavier waves; while in the torrid zone, for a similar reason, the heavier waves are on the western shores. The average force of breakers on the eastern shores of the temperate oceans is about 600 pounds to the square foot in summer, and about 2,000 pounds in winter, when the winds are stronger.

The force of the waves at the eastern end of Lake Erie has been sufficient to tear from its bed in the masonry at Buffalo harbor a rock weighing half a ton, and after moving it several feet, to turn it upside down. In the Shetland Islands, in the eastern part of the Atlantic, storm waves have torn blocks of stone weighing from 5 to 19 tons from their natural beds 70 feet above sea-level, and carried them many feet inland; while at Wick, on the north-east coast of Scotland, a mass of masonry weighing 1,350 tons was removed entire from the end of the breakwater by repeated blows of storm waves in December, 1872, and a mass weighing 2,600 tons was similarly removed in 1877.

Tides.—An observer on the shore soon recognizes the existence of other wave-like movements of the sea, quite different from that of wind waves. These movements are called the *tides*. Tidal waves differ from wind waves in being more regular, and in being much longer in proportion to their height. They are so long that, although they travel much faster than wind waves, it takes about twelve hours for one to travel its length. They are so flat that, upon the open coast, they never form breakers as the wind waves do.

The approach of the crest of a tidal wave is indicated on the shore by the gradual rise of the sea surface, and the flooding of great areas of low coast; hence, the front slope of the tidal wave is called *flood tide*. When the crest arrives at the shore, the sea surface, having nearly reached the top of wharves and piers, stops rising. It is then *high tide*. In a short time the sea surface gradually sinks, and the water slowly flows off or ebbs away from the sub-

Fig. 48.—High and Low Tides.

merged flats, giving rise to the name *ebb tide* for the front slope of the *trough* of the tidal wave. The arrival of the trough marks *low tide*, for the sea surface stops sinking and soon begins to rise on the front slope of the following crest, and the phenomena are repeated.

Tidal Currents.—Tidal waves differ, also, from wind waves in the movement of the water. Wind waves cause no current by which a floating cork is carried any great distance during the passage of a wave. Tidal waves, on the contrary, are created by strong currents, in which water is carried forward long distances on the crest of the wave, and backward long distances in its trough.

The movement of a floating cork during the passage of a tidal wave describes a greatly elongated oval; thus, suppose *A, B, C*, etc., (Fig. 49), to be equally distant points in a tidal wave advancing to the right. Suppose a cork to be floating at *A*. The points *b, c, d*, etc., indicate the position of the cork when the corresponding points of the wave *B, C, D*, etc., respectively pass under it. It will be noticed: (1) That when above half tide level the cork moves forward; when below that level, it moves backward. (2) That at half tide level (*A* and *f*) there is the most rapid rise or fall, but little or no current; hence, this stage of the tide is called *slack water*. (3) That near high tide (*c, d*) and low tide (*h, i*) there is little rise or fall, but the current is swiftest.

Depths of Water Disturbed by the Tide.— While wind waves disturb only a thin layer of the surface water, the tidal waves are caused by movement in the water clear to the bottom of the deepest sea. The lesser movement, or the rise and fall of the tide, decreases from the surface to the bottom; but the greater forward and back movements, or the tidal currents, exist at all depths. The current is slower near the bottom on account of the increased friction.

Length and Velocity of Tidal Waves.— The length of a tidal wave, and the speed at which it travels, are greater in deep than in shallow water. Its speed is such that, except in very shallow water, the wave travels its length in 12 hours and 26 minutes, or about half a day; hence, tides are semi-diurnal. Really, each wave requires 26 minutes more than half a day to travel its length; hence, each second wave arrives at the shore about 52 minutes later than the wave of the day before.

In water three miles deep, the tidal wave is nearly 6,000 miles long, and travels nearly 500 miles an hour. In

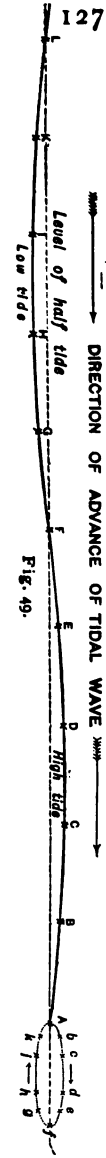


Fig. 49.

water 40 feet deep the wave is but 300 miles long, and travels but 25 miles an hour. At high and low tide the speed of the tidal currents is as great as that of the tidal wave, and this accounts for the energy which the tidal currents display in piling up bars or scouring out channels about the mouth of harbors. At other stages of the tide, however, the tidal currents are much slower than the tidal wave. In Fig. 49 it may be noticed that the cork travels only from A to f while the wave is traveling from F to f. But in the diagram the length of Af is greatly exaggerated; in the deep open sea, Af is only about 600 feet, while Ff is about 3,000 miles; hence, in such a locality the *average* speed of the tidal current is but 100 feet an hour, though the wave travels 500 miles an hour.

Height of Tides.—In the deep open sea, the rise and fall of the tide is quite insensible; it is probably less than two feet. When the tidal wave strikes the coast, however, its slight rise and fall becomes perceptible by comparison with the immovable land. The first land encountered by the tidal wave advancing from seaward are the ends of the capes which project farthest into the sea. At these points the rise and fall of the tide is generally less than at any other point of the coast, for as the currents on the crest of the tidal wave carry the water forward into the bay between two adjacent capes, the water can find room for itself, as the bay becomes narrower and shallower, only by rising higher.

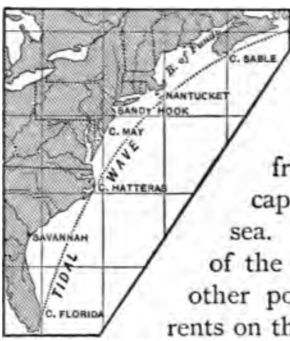


Fig. 50.

Thus, the tidal wave of the Atlantic (Fig. 50) reaches capes Florida and Hatteras, and Nantucket Island at about the same time. At each of these points the rise and fall of the tide is between one and two feet, while at Savannah and at Cape May, near the heads of the intervening bays or bights, the height of the tide is 7 and 5 feet respectively. This effect is still more marked in the Bay of Fundy, where, entering with a height of 8 or 9 feet, the tidal wave gradually increases to a height of over 40 feet at the head of the bay.

Duration of Flood and Ebb Tides.—Upon open coasts the front and rear slopes of the tidal wave are nearly equally steep, and the trough is about half-way between the two crests; hence, the flood and ebb tides are of equal duration—each about six hours. In comparatively shallow and gradually narrowing bays, the slopes become steeper, for the wave length is less and its height greater; and, as the water when in the crest of the wave, being farther from the bottom and less retarded by friction, moves forward faster than it moves backward when in

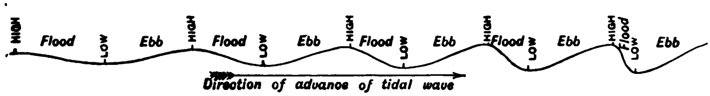


Fig. 51.

the trough, the wave gradually changes its shape as it advances, as indicated in Fig. 51. Therefore, in bays and estuaries the flood tide is generally of shorter duration than the ebb tide. Thus, at the mouth of Delaware Bay the flood and ebb tide each continues for about six hours; at Newcastle, Delaware, the tide rises for $5\frac{1}{2}$ hours and falls for about 7 hours, while at Philadelphia the flood lasts less than 5 hours and the ebb more than $7\frac{1}{2}$.

The shape, depth, and situation of some estuaries is such that the front slope of the tidal wave becomes so steep that the crest falls forward into the trough, giving the flood tide the form of a breaker called the *bore*, which advances up the estuary at the great speed of the wave. In this case the flood tide is but momentary, while the ebb lasts about twelve hours. In the deep channel of the estuary, the tide may advance as a steep wave, and along its shallower margins as a breaker or bore. The bore is seen at the head of the Bay of Fundy, in the Hoogly mouth of the Ganges, in the Dordogne in France, the Severn in England, the Amazon in Brazil, etc.

Races.—Since the height of the tidal wave depends so largely upon the shape of the adjacent shores and the

depth of the water, the same wave may rise to very different heights in neighboring bays on the same coast. If the heads of these bays are connected by a narrow channel, the difference in water level in the two bays will give rise to a *race*, or strong current, in the channel, flowing at high tide, out of the bay in which the tide is highest. But at low tide the water is lowest in this bay; hence, the direction of the race is reversed with each change of tide.

Such races are common on all irregular coasts, especially when fringed with islands. Such are the famous "Maelström" among the Lofoden Islands, the currents of Pentland Firth north of Scotland, and those of Hellgate, in the narrow channel between Long Island Sound and New York Bay. If the waters of the Sound could be separated from those of the Bay by a partition at this point, the water at high tide on the Sound side would stand 5 feet higher, and at low tide 5 feet lower than the water on the Bay side.

Cause of the Tides.—The great regularity in the recurrence of the tidal wave denotes that it must be caused by some constant and regular force; and the fact that the water to its greatest depths is disturbed by it indicates that this force can not be a merely superficial one, like the wind. A force, constant, regular, and not superficial is found in the mutual attraction of gravitation between the earth, the moon, and the sun, and it is the peculiar effect of this force upon the liquid sea which results in the tidal wave. As the effect of the moon is usually most prominent, it is common to speak of the tides as caused solely by the moon. They are, however, always modified to a greater or less extent by the sun and the earth.

Let *A B D C* (Fig. 52) represent the earth and let *M* represent the moon. The gravitation of the moon attracts every particle of the earth with a force which varies inversely with the square of the distance between the particle and the moon, the average attraction being that exerted on the particle at the earth's center, *E*. It is obvious that the moon's attraction on the side of the earth which is turned

towards and is hence nearer to the moon is slightly greater than the average, while the attraction on the more remote side of the earth is slightly less than the average. There is consequently a tendency for the particles on the side of the earth towards the moon to move towards that luminary, and for the particles on the remote side of the earth to move away from the moon. The solid land resists this tendency to move, but the liquid sea yields to it, and slow movements throughout its depth set in from all directions toward *C* and *B*, by which the sea surface is slightly raised to *H* and *F* at points on opposite sides of the earth and correspondingly lowered to *I* and *K* along the meridian *AED*, half-way between *H* and *F*.

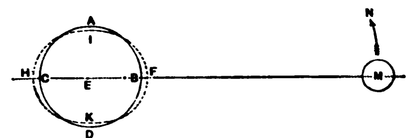


Fig. 52.

Owing to the earth's rotation, the points on its surface, towards which the tidal currents are moving, are constantly changing, and after about six hours, *A* and *D* occupy the positions of *C* and *B*, *I* and *K* being then elevated, and *H* and *F* depressed; that is, the currents in the sea which before moved away from *A* and *D* are reversed, and now move toward these points. About six hours later, when *C* occupies the position of *B*, the currents are again reversed, and so on. This regular reversal of the slow currents of the sea, which for about six hours advance from all directions toward a point, and then for a like time retreat in both directions away from this point, produces the long, low tidal wave, whose period of passage is always about twelve hours,—six hours for the crest and six hours for the trough. Tides occur later each day because, while the earth is making a rotation, the moon is advancing in the same direction in her orbit; hence, the earth has to make a little more than a complete rotation to present the same point of its surface directly to the moon. For precisely similar reasons the sun also produces a tidal wave, but it is less than one half as high as that produced by the moon; for, although the sun's attraction is much greater than the moon's, it is so much farther away that the diameter of the earth is relatively insignificant, and his attraction on opposite sides of the earth is nearly the same. Once a week, however, the existence of the solar tide becomes apparent. The moon makes a complete revolution about the earth in four weeks; twice during this time—at new and full moon—the attraction of the sun and of the moon combine to

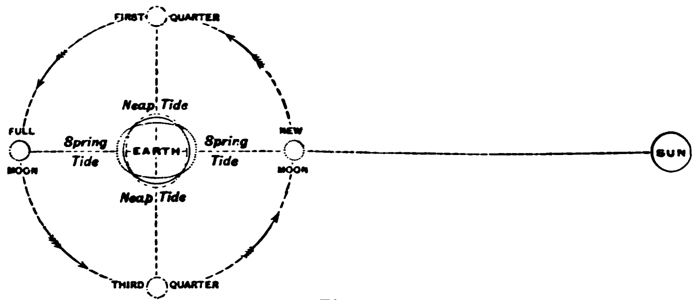


Fig. 53.

produce an unusually high tidal wave called the *spring tide*. At two other points in the moon's orbit—first and third quarters—the crest of the solar occurs in the trough of the lunar tidal wave, the combination resulting in an unusually low tidal wave, called the *neap tide*. The weekly change in the height of tidal waves is:

Head of Bay of Fundy,	*Spring Tide*,	50 feet.	*Neap Tide*,	24 feet.
Boston, Mass., . . .	"	11.3 "	"	8.5 "
New York, N. Y., . .	"	5.4 "	"	3.4 "
Cape May, N. J., . .	"	6.0 "	"	4.3 "
Cape Hatteras, N. C., .	"	2.2 "	"	1.8 "
Savannah Entrance, Ga., .	"	8.0 "	"	5.9 "
Cape Florida, Fla., . .	"	1.8 "	"	1.2 "
San Francisco, Cal., . .	"	4.3 "	"	2.8 "
Astoria, Oregon, . .	"	7.4 "	"	4.6 "

Establishment of the Port.—The currents moving under the attraction of the moon to form the crest of the tidal wave, or high tide, are prevented by their momentum from stopping immediately when under the attracting body. Besides this, the point under that body is constantly advancing westward on account of the earth's rotation; hence, the crest of the wave is always east of the meridian under the moon. The momentum depends upon the speed of the water and its amount, *i. e.*, upon the depth and shape of the bottom. Hence, though the interval of time is always the same between the passage of the moon

over a given locality and the arrival of high tide, this interval varies at different localities. It can only be found by observation, and when found is called the *establishment of the port.*

Thus, the establishment of the port of Boston is 11 hours, 27 minutes; of New York, 8 hours, 13 minutes; of Cape May, 8 hours, 33 minutes; of Washington, 7 hours, 44 minutes; of Cape Hatteras, 7 hours, 4 minutes; of Savannah Entrance, 7 hours, 20 minutes. Each indicates the time intervening between the moon's transit at that point and the arrival of the succeeding high tide.

Diurnal Inequality of the Tides.—The inclination of the earth's axis to the orbit of the moon tends to produce a periodical inequality in the heights of the two daily tide waves. This is called the *diurnal inequality.* Every two weeks, when the moon is over the equator, both waves are of equal height, but in the intervening time one wave tends to become higher than the other, and the wave that is highest during the fortnight that the moon is north of the equator is lowest during the following fortnight when the moon is south of the equator. Owing to the shape of the Atlantic, the effect of the diurnal inequality is not very perceptible in that ocean, but it is a marked feature on the Pacific Coast, and its effect is seen in the Gulf of Mexico, where it causes only a single tide a day to be perceptible, and that only at the times when the moon is some distance north or south of the equator.

Fig. 54 (page 134) shows the record, during a fortnight, of tide guages at San Francisco and the mouth of the Mississippi River respectively. Each of the vertical spaces represents one day, while the rise and fall of the tide is represented by the curved lines. It is seen that at San Francisco there are two tides each day, but one of them is considerably higher than the other, excepting about the time when the moon is over the equator. The wave (indicated by dots in the diagram) which is highest when the moon is north of the equator, is lowest when the moon is south. The semi-diurnal tides of the Atlantic approach the Gulf of Mexico

by the two channels on either side of Cuba. The shape and depth of these channels is such that the tide wave travels through them at unequal speed. Thus, the crest of the wave from one channel, and the trough of the wave from the other, enter the Gulf simultaneously. They therefore neutralize each other, except when the moon is far from the equator, and the diurnal inequality makes the waves of unequal heights. At such times this difference of height is propagated through the Gulf as a small diurnal wave, while, when the moon is near the equator, no tides are perceptible.

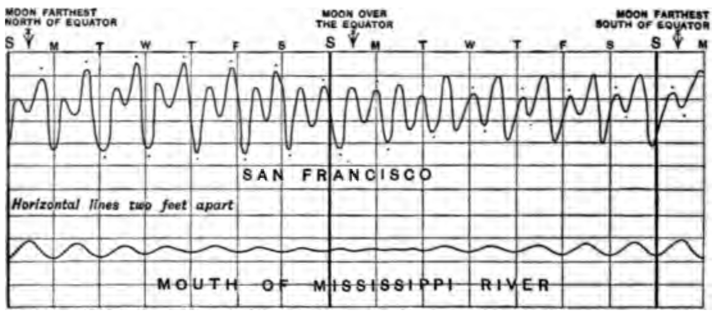


Fig. 54.

Tides in Lakes and Landlocked Seas.— As the force which produces the tides is universal, it affects all water surfaces on the face of the earth, but in even the largest sheets of water completely cut off from the sea, as the Caspian Sea and Lake Superior, the length of the water surface is so insignificant in comparison with the length of the tidal wave (half the circumference of the earth) that the variation of level in the small part of the wave formed in them is quite imperceptible.

Even in the long Mediterranean, the height of the tidal wave on open coasts is only 3 or 4 inches, and is generally obliterated by the wind. The converging shores render the tides more perceptible near the head of the Adriatic and in the Straits of Messina, where the eddies and currents "between Scylla and Charybdis" resemble those of Hellgate, New York.

CHAPTER X.

CURRENTS AND DEPOSITS.

They that go down to the sea in ships, that do business in great waters; these see the works of the Lord, and his wonders in the deep.—PSALM CVII: 23, 24.

Currents.—In addition to the forward and back movement of the water in wind and tidal waves, each ocean is traversed by systems of *true currents*, or continuous movements of the water in the same direction. Several causes combine to produce these continuous currents; the principal cause, however, is the inequality in the density of the water in different parts of the sea, arising from differences in temperature and saltness.

Effect of Temperature.—Since water expands and becomes less dense when heated, the surface of the sea stands somewhat higher near the tropics than in the frigid zones, where the water is 40° or 50° colder. Gravity gives the *surface* water a tendency to flow down the gentle slope thus formed, from the tropics toward the nearest pole, while the increased pressure upon the deeper water caused by the arrival in higher latitudes of the surface water from the tropics, gives the *deeper* water a tendency to flow back toward the tropics. These movements are facilitated by the fact that the deep polar water is more salty, colder, and hence heavier than the deep water of lower latitudes, while the polar surface water, though colder than the surface water at the tropics, is not so dense or heavy, because the melting ice renders it less salty.

Effect of Saltness.—The constant trade winds start from the tropics very dry, but arrive at the equatorial calms saturated with vapor. Rising over these calms, the vapor condenses and causes almost constant rains. Since vapor is perfectly fresh, the region of the sea from which it is taken is left more salty, and the region on which it is precipitated as rain is made less so; hence, the surface water near the tropics is more salty and heavier than that in the equatorial calms. The tropical surface water, heavy through its excess of salt, can not sink far because the deeper water is equally heavy from its lower temperature; it consequently moves toward the equatorial calms to displace the lighter water there.

Thus, the varying temperature and saltness of the water in different parts of the sea give the *surface* water a general tendency to move toward the equator in the torrid zone, and toward the poles in the temperate and frigid zones; and to the *deeper* water, in all zones, a general tendency to move toward the equator.

The direction in which ocean currents flow is greatly modified, however, by (1) the rotation of the earth; (2) the configuration of the coast and sea bottom; (3) by other currents; and (4) by the winds.

The rotation of the earth gives to moving water, as it does to moving air (page 79), a tendency to turn out of a straight course. In the northern hemisphere it tends to turn to the right, and in the southern hemisphere to the left. This tendency affects moving water at all depths, and increases from the equator to the poles.

The coast of an ocean deflects currents at all depths which flow against it. If the current strikes the shore almost at right angles, part of it is deflected to the right and part to the left. The configuration of the sea bottom influences the direction of deep water currents in the same way, for as the heaviest water sinks to the bottom, this water, when moving as a current, can not rise through the lighter water above to pass over submarine banks or ridges, which therefore deflect currents in the deeper water.

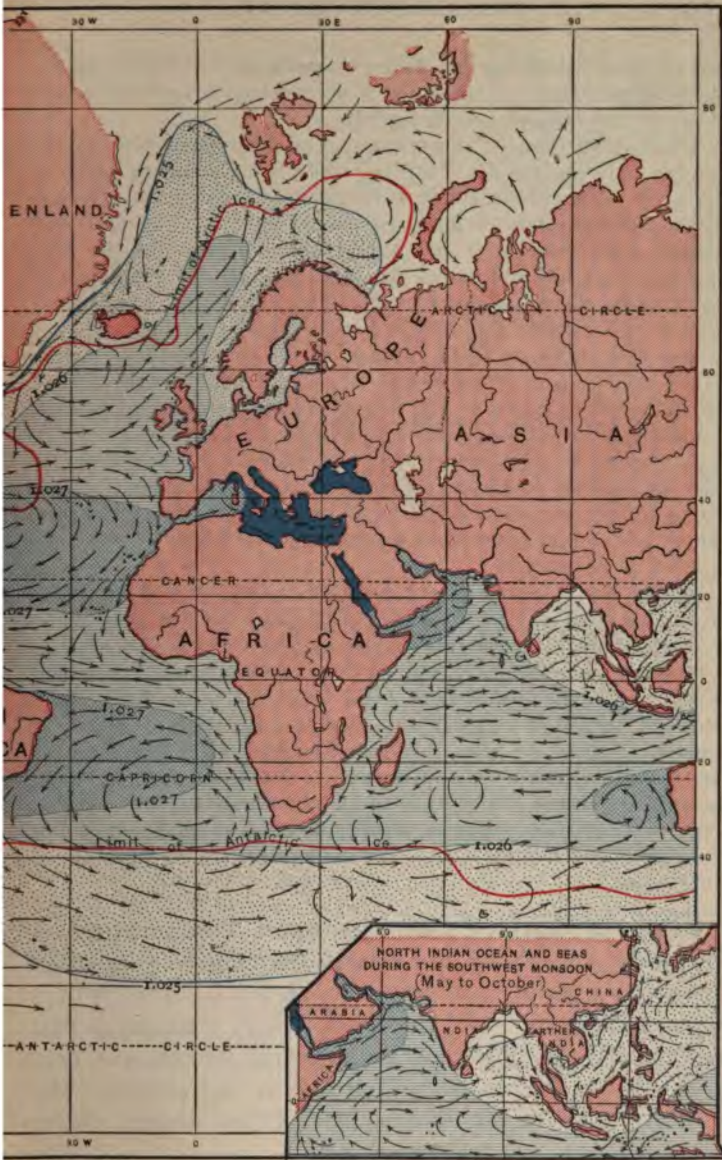
A current meeting another at any angle deflects it, and is itself deflected to the right or left, or in both directions, according to the angle of meeting and the respective strength of the currents.

The friction of the wind on the sea surface tends to move the water in the direction of the wind. If the wind moves in the same direction as the current, it tends to make the current move faster; if it blows obliquely across the current, it tends to deflect the current; if it blows against the current, it tends to check and may even reverse for the time being a gentle flow. The effect of the friction of the wind is always superficial, however; Professor Ferrel estimates that its influence immediately beneath the surface is less than $\frac{1}{100}$th of that arising from unequal density of the water.

Surface Currents.—In consequence of these modifying influences, the general movement of the surface water in each of the oceans is outward and around the tropical regions where the surface water is densest and heaviest, the currents thus forming great outward moving whirls similar to anticyclones in the atmosphere. The general movement of these whirls is westward on either side of the equatorial calms, away from the equator in the western part of the oceans, eastward between latitudes 40° and 60°, and toward the equator in the eastern part of the oceans. In the narrow region of equatorial calms a "counter-current" moves eastward in all the oceans. Beyond latitude 50°, in the southern hemisphere, there is but little land to deflect the movement of the surface water from its general easterly course around the globe. In the higher latitudes of the northern oceans, however, and especially in the Atlantic, with its Arctic extension, the easterly moving water between 50° and 60° latitude encounters the west coasts of the continents. Part of it is deflected northwardly along these coasts, thus causing a southward return current along the east coasts of the continents in these higher latitudes.

While the movement of surface currents is generally similar in all the oceans, differences in the shape and extent of the coast-line,


RELATIVE DENSITY
of the Surface Water,
THE SURFACE CURRENTS
and Equatorial limits of
FLOATING ICE
in the various parts of the Oceans
ASIA
ARCTIC CIRCLE
Arctic Ice
NORTH AMERICA
TROPIC
EQUATOR
AUSTRALIA
NEW ZEALAND
1.025
1.026
1.027
EXPLANATION
Specific Gravity less than 1.025
" " 1.025 to 1.026
" " 1.026 to 1.027
" " 1.027 to 1.028
" " more than 1.028
The arrows fly with the current.
A square mile of water 1 foot deep with a Sp. Gr. of 1.027 is about 850 tons heavier than an equal volume with a Sp. Gr. of 1.026.
150 E
180
150 W
120
90
Folger Eng. Co.



30 W
0
30 E
60
90
ENLAND
1.025
Limit of Arctic Ice
ARCTIC CIRCLE
1.026
EUROPE
ASIA
1.027
CANCER
AFRICA
EQUATOR
1.027
CA
CAPRICORN
1.027
Limit of Antarctic Ice
1.026
1.025
ANTARCTIC CIRCLE
NORTH INDIAN OCEAN AND SEAS
DURING THE SOUTHWEST MONSOON
(May to October)
CHINA
ARABIA
AFRICA

and in other modifying influences, cause local peculiarities in the speed, temperature, and constancy of the currents in each ocean, and these vary at different seasons of the year.

The Gulf Stream.—The western part of the tropical whirl in the Atlantic is called the Gulf Stream, and off the southern coast of Florida it is made one of the most rapid of ocean currents by the peculiar configuration of the coast in that vicinity. The equatorial current enters the Gulf of Mexico through the broad, deep Yucatan Channel, and forces an equal amount of water to flow out through the Strait of Florida. This strait being relatively shallow and narrow, the outflow is more rapid than the inflow.

The Kuro Siwo, or Black Stream, as the corresponding current in the western part of the Pacific is called, though a well marked current, is not so strong or well marked as the Gulf Stream because of the chain of islands which border the east Asiatic coast—Formosa, Japan, etc.,—among which part of the current is deflected from its regular north-easterly course, and also because of the strong winter monsoon of that region, which at that season diverts part of this current to the south-west through the Malay Archipelago into the Indian Ocean.

In the North Indian Ocean the effect of the monsoons upon the surface currents is very marked. In January the north-east monsoon strikes the northern part of this ocean as a dry land wind, and evaporating water rapidly, renders the surface water salty and heavy. Aided by the friction of the wind, the water flows southwestward toward the lighter and fresher water in the region of equatorial calms and rains. In July, however, the south-west monsoon, rendered damp near the equator, pours down fresh water on the northern part of the ocean, and the salter and heavier equatorial water, aided by the friction of the winds, flows north-eastward and along the coast into the China Sea to augment the strength of the Kuro Siwo.

Effect of Surface Currents upon Temperature.—The water composing the surface currents is warmed in equatorial regions, and arrives in higher latitudes with a higher temperature than the sun is able to maintain at that latitude. It therefore cools by imparting its excess of heat to the water below and the air above, and arrives at the equator again, in the eastern part of the oceans, cooler

than the equatorial air and water. These are slightly cooled by imparting heat to the cooler current, and aiding the sun to warm it again during its westward flow across the ocean. Thus, all currents tend to moderate the temperature of the region they traverse; if they come from a warmer region, they tend to raise the temperature; if from a colder region, to lower it. It has already been stated (page 61) that about one half of the heat received by the whole torrid zone is carried by ocean currents into colder latitudes.

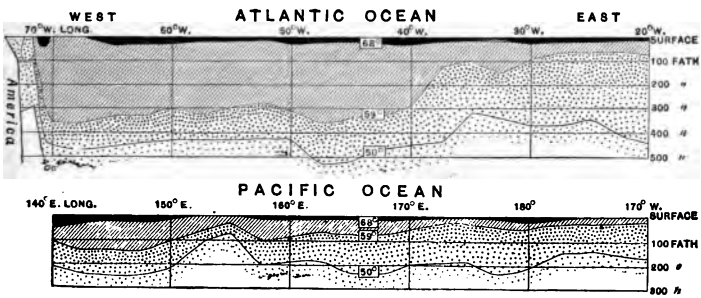


Fig. 55.

Since the currents between the equator and about 45° latitude move from the equator in the western part of the oceans and toward the equator in the eastern part, it follows that the western part of the oceans in these latitudes contains a greater amount of warm water than the eastern part. This is well shown in the temperature sections across the Atlantic and Pacific oceans along the parallel of 35° north latitude (Fig. 55). A temperature higher than 59° extends to a depth of over 300 fathoms in the western part of the Atlantic, but to scarcely 100 fathoms in the eastern part. Owing to the less relative strength of the warm current in the Pacific (the Kuro Siwo), and the greater size of that ocean, the isotherm of 59° lies at a less depth in the Pacific than in the Atlantic; but while it reaches a depth of nearly 150 fathoms in the western part of the ocean, it rises to within less than 50 fathoms in the eastern part. In higher latitudes, on account of the reversed directions of the cur-

rents, the waters of the North Atlantic and Pacific are warmer in the eastern than in the western parts of these oceans. In the Atlantic a narrow branch of the [illegible] polar current follows the American coast southward to the latitude of the Carolinas, forming a "cold wall" of water between the warm Gulf Stream and the shore. The cold southwardly flowing current in the high latitudes of the western Atlantic brings vast numbers of icebergs down to the neighbourhood of Newfoundland, where, meeting the warmer waters of the Gulf Stream, the bergs melt rapidly and deposit their load of rocky material. This deposit, gathering through untold ages, has [illegible] the shoals [illegible] called the *Newfoundland Banks.*

Deep Sea Currents.—The systems of surface currents affect [illegible] a comparatively thin layer of water. Their [illegible] greater depth than a few hundred fathoms. The movements of the great mass of sea-water below this depth [illegible] be directly observed, but progressive movements or currents are known to exist because of its temperature.

[illegible] comparatively thin layer of surface water is directly [illegible]. [illegible] however, affects the [illegible] deeper water [illegible] the temperature of the sea [illegible] depths, that is [illegible] and [illegible] than [illegible] warmer [illegible]

[illegible] Deep Sea Currents.—

[illegible]

ness, otherwise the finely powdered material which composes the bottom of the ocean would be swept away by them.

The only places where the Arctic water could flow south are between Europe and America into the Atlantic, and through Behring Strait into the Pacific. But a submarine ridge, on which Iceland stands, extends entirely from Europe to America. It rises everywhere to within 500 fathoms of the surface, and therefore prevents the deeper water of the Arctic from entering the Atlantic. East of Iceland all the water above the top of the ridge is warmer than 40°, and moves northwardly; hence, it is only in the comparatively narrow channels between Iceland and Labrador, and in the entirely insignificant Bering Strait, that any of the cold surface water of the Arctic escapes southwardly.

Theory Confirmed.—The theory that the low temperature of the deeper water in the sea is produced by cold under-currents from the polar regions, is confirmed by the comparatively high temperature of the deeper water in regions which such under-currents can not enter on account of an intervening submarine ridge. The Mediterranean and Caribbean seas are such regions, as well as several of the east Asiatic seas, and perhaps the whole north Pacific Ocean.

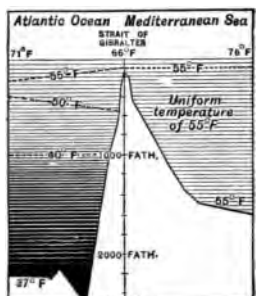


Fig. 56.

As indicated in Fig. 56, the temperature of the Atlantic opposite the Strait of Gibraltar falls continuously from over 70° at the surface to about 37° at the bottom in 2,200 fathoms. The Strait of Gibraltar, with a depth of less than 200 fathoms, admits to the Mediterranean no water colder than 55°. The deep basin of the Mediterranean is thus filled with water no colder than that which enters in the lower part of the inlet current from the Atlantic with a temperature of 55°. Hence, the temperature of the Mediterranean falls continuously only from the surface to the depth of the bottom of the inlet current (about 125 fathoms),

beyond which, clear to the bottom (over 2,000 fathoms in some places), the temperature of the water is uniform at 55°. A uniform temperature of 39½° was long since observed in the Caribbean Sea and the Gulf of Mexico at all depths greater than about 1,000 fathoms. The existence of a channel to the Atlantic, with a depth of about 1,000 fathoms, was therefore inferred, although all known channels were much shallower. In 1884, however, a channel between Puerto Rico and Santa Cruz was discovered having a depth of 926 fathoms, and a bottom temperature of 39½°. The deep seas of the Malay Archipelago have uniform temperatures below depths varying from 400 to 900 fathoms, from which it is inferred that each of these seas is inclosed by a submarine ridge, whose lowest point corresponds to the depth at which the uniform temperature begins. All temperature observations in the Pacific north of a line from northern Chile to China, indicate a uniform temperature below a depth of 1,500 fathoms, while to the south of this line the temperature decreases constantly to the bottom. Hence the inference that a submarine ridge, rising to within at least 1,500 fathoms of the surface, unites South America with Asia, and prevents the cold bottom water of the Antarctic from entering the North Pacific.

Currents between the open ocean, and nearly inclosed arms of the sea, depend to a great extent, like the surface-currents in the open ocean, upon evaporation and precipitation. If more water falls in the basin of the partially inclosed sea than is evaporated from its surface—as in New York Bay and the Baltic and Black seas—its surface tends to rise higher than that of the ocean, and a current from the bay or sea into the ocean is the result. If, however, less water is precipitated in the basin of the sea than is evaporated from its surface, as the Mediterranean and Red seas, the surface tends to fall below the ocean level, and a current from the ocean into the sea is the result.

In the latter case, since only fresh water is removed by evaporation, and since the level of the inclosed sea is maintained by a flow of salt water from the ocean, the tendency is for the sea to become constantly more salty. Both the Mediterranean and Red seas are more salty than the ocean, but their water does not appear to in-

crease in saltness. The tendency to increase in saltness must therefore be counteracted by a current which carries just enough of the excessively salty water of the inclosed sea into the ocean to prevent a constant increase of saltness. As the inclosed sea water is heavier than the fresher ocean water, the outflowing current occupies the bottom, and the inflowing current the top of the channel by which the sea communicates with the ocean. Therefore, the uniform temperature in the Mediterranean begins, not at the depth of the Strait of Gibraltar, but at the depth of the bottom of the inflowing current; for the outflowing under-current is as effectual a barrier to the entrance of colder ocean water as the submarine ridge itself.

Deposits of the Sea.—In addition to the solid matter dissolved in sea-water, which gives it the salty and bitter taste, there is always a quantity of solid matter, in coarser or finer grains, which is gradually sinking through sea-water, and forming a deposit on the bottom. This sediment is derived chiefly from three sources: (1) the continents, (2) the animals and plants which inhabit the sea, and (3) the material ejected from volcanoes. According as the bottom in any region of the sea is composed principally of matter derived from one or other of these sources, the deposit is called *continental*, *organic*, or *red clay*.

Continental Deposits cover about two fifths of the sea bottom. They form the sea bottom for a distance of 300 or 400 miles from the shores of all the continents and continental islands, and extend completely across the polar oceans and all partially inclosed seas. They consist of variously colored muds, composed principally of very minute rounded fragments of the rocks which constitute the land. These muds also contain organic remains and volcanic minerals.

Fig. 57.

Fragments from continental deposit, magnified ten times, are shown in Fig. 57. Pieces of the rocky coast are being constantly broken off and ground to powder by the force of the waves, while

Fig. 58.—Globigerina Ooze.
(*Magnified* 13 *times*.)

Fig. 59.—Pteropod Ooze.
(*Magnified* 3 *times*.)

the water of every stream is more or less muddy, according as its current is carrying or rolling along a greater or less amount of rocky, earthy, or other continental material. The larger fragments broken off by the waves or brought down by the rivers, sink to the bottom near the shore of the ocean, to be rolled about and ground finer by the waves; but the finer pieces sink more slowly, and are carried farther away by the ocean currents. It is only in exceptional cases, however, such as floating ice, etc., that even the most minute fragments are carried more than 300 or 400 miles before they settle to the bottom.

Fig. 60.
Radiolaria Ooze.
(*Magnified* 50 *times*.)

Fig. 61.—Diatom Ooze.
(*Magnified* 100 *times*.)

Organic Deposits differ from continental deposits in containing no remains of continental rocks. An organic deposit constitutes the bottom in such portions of the sea as lie beyond the limits of the continental deposits, and have a depth less than 2,900 fathoms. It is a soft, fine mud, or *ooze*, composed principally of the shells or stony framework of minute organisms which live near the surface of torrid and temperate seas. It is called *globigerina*, *pteropod*, or *radiolaria* ooze, if the shells of these animals respectively are most numerous, or *diatom* ooze if the stony frustules of this plant are in excess.

The shells or stony frame-work of sea organisms are largely composed of carbonate of lime, extracted from sea-water during the life of the organism; at death these stony structures begin to sink, and are slowly dissolved again by the sea-water. If the sea is deeper than about 2,900 fathoms, the calcareous or limy portions are entirely dissolved before they reach the bottom; but if of less depth, fragments of them may reach the bottom and be covered up and protected by following pieces. Hence, organic deposits are always calcareous, sometimes being nearly pure carbonate of lime.

Fig. 62.

Red Clay Deposits differ from continental and organic deposits in the general absence of continental débris and calcareous organic remains. The red clay covers the sea bottom beyond the limit of the continental deposits, in depths greater than 2,900 fathoms. It is a stiff clay, greasy to the touch, plastic when wet, but very hard when dry. It is composed almost exclusively of the minerals which are found in volcanic rocks. Most of the minute mineral fragments found in it are sharp and angular, (Fig. 62, magnified 100 times,) in marked contrast to the rounded fragments of the continental deposits. The surface of the deposit is strewn with pieces of pumice stone, minute particles of magnetic iron of meteoric origin, and with great numbers of the hardest bones of sea animals, as the ear-bones of whales and the teeth of sharks, some of which belong to species once plentiful but long since extinct. The older bones are covered with a thick coating of oxide of manganese, while the bones of more recent species are quite clean. Figure 63 shows the incrusted tooth of a shark, and Figure 64 the incrusted ear-bone of a whale.

Fig. 63.

Fig. 64.

The volcanic materials which compose the red clay are derived from pumice stone, which is so light that it floats for great distances before sinking; from volcanic ashes, which are carried to great distances by the winds; and from volcanic lavas and tufas laid down directly on the sea bottom. All these volcanic products are rich in the minerals of which clay is composed, and these minerals, being liberated by the chemical action of the sea-water, reunite in the proportions to form the red clay.

What the Deposits Teach.—The character of the various deposits goes far toward confirming the belief that the present ocean basins have been depressed regions, and that the present continents have been elevated regions continuously, from a very early period of the earth's history; but while the present regions of organic and red clay deposits have always been covered by water, the marginal region of continental deposit, as well as the present land, have been subjected to many upward and downward movements, by which large areas of each have been alternately raised above and lowered beneath the surface of the sea. Thus, the continents and the oceans, though constantly varying somewhat in shape and size, have always maintained their present general arrangement.

The great antiquity of the red clay deposit, and the extreme slowness with which it collects, are indicated by the abundance of meteoric fragments, and whales' and sharks' bones, many of them of extinct species and deeply incrusted, which are found on the surface of this deposit. Great numbers of fragments and bones probably settle upon the other deposits also, but are covered up and buried in the more rapidly accumulating continental and organic debris. Most of the rocks of the continents bear evidence of being a hardened sea deposit very similar to the continental deposits now forming, but no rocks have been found similar to organic and red clay deposits of the deep open ocean. From this it is inferred that most of the continental rocks were formed as a continental deposit beneath the surface of the sea like the present continental deposits, at no great distance from the land, and afterward elevated above sea-level. Such gradual elevation or subsidence of coast regions is now in actual progress in many parts of the earth.

PART IV.—THE LAND.

CHAPTER XI.

DIVISIONS OF THE LAND.

And God said, Let the waters under the heaven be gathered together unto one place, and let the dry land appear: and it was so.—GENESIS 1: 9.

Comparative Smoothness of the Earth's Surface.—In speaking of the earth as a whole, its solid surface was considered as being perfectly smooth, and in comparison with the vast dimensions of the planet, the irregularities of its surface are insignificant. These irregularities are of vast importance, however, since they cause the division of the surface of the earth into areas of sea and land.

The relative insignificance of the surface irregularities can be appreciated from the diagram on the next page (Fig. 65), in which the heights and depths have been *exaggerated ten times.*

The Land.—The tops of the highest irregularities on the earth's surface protrude above the surface of the sea and form land. The total land area of the world is about 52,500,000 square miles, and constitutes but little more than one fourth (26⅔%) of the surface of the planet.

The Level of the Sea.—The sea has a smoother surface than the solid globe. Though always slightly roughened by waves, it never varies more than a few feet from perfect smoothness. Its mean height when half-way between low and high tide is usually adopted as the base,

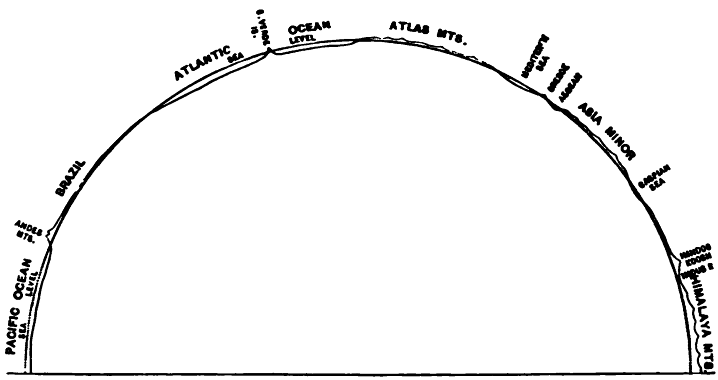


Fig. 65.—The Proportional Roughness of the Earth's Surface Exaggerated Ten Times.

called *sea-level*, from which all differences of elevation in the earth's solid surface are measured.

Regions of Elevation and Depression.—The mean height of the land above sea-level is a little less than one half a mile. As the mean depth of the sea is 2½ miles, the total mean height of the land above the sea floor is about 3 miles. An elevation half as great (that is, 1½ miles above the sea floor), may therefore be taken to divide the regions of *elevation* in the earth's crust from the regions of *depression*. In other words, not only the land, but all parts of the sea bottom on which the water is less than 1 mile deep, are to be considered as regions of elevation, while only the sea bottom at greater depths is to be considered the region of depression. This region of depression is shown in solid black in the map on pages 152 and 153; the regions of elevation are shaded or are left white.

Region of Elevation.—The map shows that there is but one great region of elevation. It extends entirely across the northern hemisphere, and at three places pene-

trates the southern hemisphere to about 40° south latitude. The height of this continuous region of elevation is not uniform; at certain localities it does not reach quite to the level of the sea, but enough of it protrudes above the sea to constitute almost all ($\frac{993}{1000}$ths) of the land on the globe. It may therefore be called the continental plateau. The only other regions of elevation rise in small, isolated areas in various localities, the largest being about the south pole, and in the tropical Pacific Ocean. Collectively, these isolated regions of elevation form but $\frac{7}{1000}$ths of the land on the globe.

The primary cause of the elevation of the continental plateau is not yet known. It seems probable that the part of the earth's crust forming this region is lighter, bulk for bulk, than the part beneath the deep sea. This of itself would probably cause the former to be a region of elevation. As explained on page 42, the earth's crust at a depth of a few miles probably behaves as if it were plastic or liquid, *if the pressures on adjacent portions of it are very unequal*, the rock particles moving or "flowing" sideways from under the region of greater pressure, until, by this transfer of matter, the weight and pressure become uniform. When the weight thus becomes uniform, the lines of equal pressure would be *level*. But to produce equal pressures, the lighter part of the crust would have to be *thicker* than the heavier part; hence its upper surface would be further above the level pressure lines below, and would form a region of elevation. The plateau crust may be composed of lighter rock than the crust of the sea bottom, or it may be lighter because it is hotter and more expanded; but science can not yet satisfactorily explain why either should be the case.

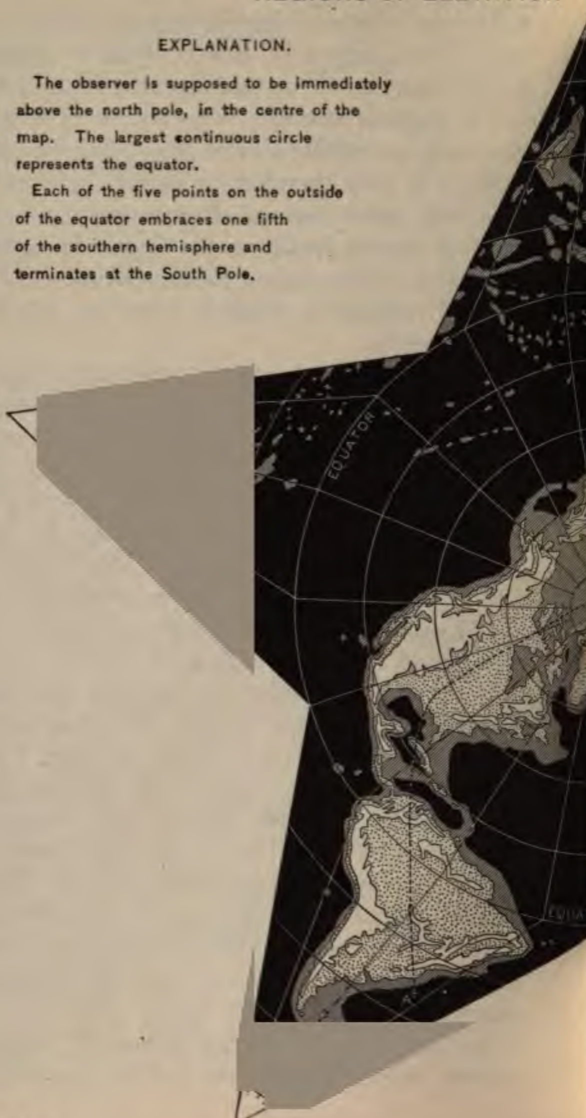
In shape, the plateau is roughly curved, like an irregular horseshoe; the toe lies in the arctic regions, and

REGIONS OF ELEVATION

EXPLANATION.

The observer is supposed to be immediately above the north pole, in the centre of the map. The largest continuous circle represents the equator.

Each of the five points on the outside of the equator embraces one fifth of the southern hemisphere and terminates at the South Pole.



AND DEPRESSION.

the two arms extend into the southern hemisphere. The line *AB* (pages 152, 153) may be regarded as the curved axis of the main portion of the plateau. The deep pocket formed in the concavity of the curve is the basin of the north Atlantic. From the outer side of the main plateau a small third arm extends into the southern hemisphere, and separates the basins of the Pacific and Indian oceans. The axis of this third arm is shown by the dotted line *CD*.

Elevation and Coast-line.—Not only is the greater part of the plateau sufficiently elevated to protrude above the sea to form land, but the highest part, indicated by the unshaded portion of the map, forms an almost continuous tract along the outside or convex margins, while the concave margins are generally low, being broken only by isolated highland regions. The convex sides of the plateau are therefore steep, and possess a very regular coast-line, while the concave side has a gentle slope, occupying the greater part of the width of the plateau, and continues beneath the sea, fringing that side with a greater width of shallow water. The coast-line of the low, concave margin is made very irregular by several deep indentations which admit the sea far on the plateau to form great continental seas. The largest of these are the Arctic Ocean, the Mexican-Caribbean Sea, the Mediterranean, and the seas of the Malay Archipelago, and they are located where the bends of the axis are sharpest.

Continents.—The depressions occupied by the Arctic Ocean and the Malay seas, extend entirely across the plateau, breaking through the high, convex margin in Bering Strait in the one locality, and in the several narrow straits between the Sunda Islands (Sumatra, Java, Timor, etc.), in the other locality. The land of the plateau is thus separated into three great, continuous

masses, or *continents*, and numerous smaller, isolated masses, or *islands*. The three continents collectively contain more than 92% of the land on the globe. The islands rising from the continental plateau are distinguished as *continental* islands; collectively, they comprise almost 7% of the land on the globe. The continents are very unequal in size; the largest, or Eastern Continent, contains about 59% of all the land; the next in size, or the Western Continent, almost 28%; and the smallest, or the Australian (southern) Continent, is the only one lying entirely in the southern hemisphere, and contains less than 6% of the land on the globe.

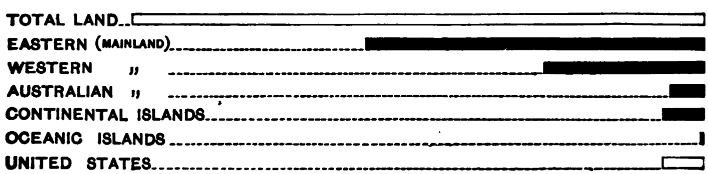


Fig. 66.—Relative Areas of Continents and Islands.

Grand Divisions.—The depression of the Mexican-Caribbean Sea penetrates to the narrow highland margin on the convex side of the plateau, and determines the two natural and nearly equal grand divisions of the Western Continent—North America and South America. A corresponding depression in the opposite arm of the main plateau is occupied by the Mediterranean, and continues across the plateau in the narrow and gorge-like depression occupied by the Red Sea. The heads of these seas almost meet at the narrow Isthmus of Suez, and thus nearly detach one third of the Eastern Continent from the rest to form the natural grand division—Africa. The remainder of the Eastern Continent strictly forms a single natural grand division—Euro-Asia.

Before the extent of the Black and Caspian seas was accurately known, their depressions were supposed to divide this grand division into two parts, which were named Asia and Europe. The error was subsequently discovered, but the names remained, and the Eastern Continent is still said to be composed of three grand divisions, though Europe occupies but little more than one tenth of its area, and the boundary between Europe and Asia is arbitrary rather than real. Each of these five grand divisions is frequently though wrongly called a continent.

Distribution of Continental Islands.—More than 85% of the area of continental islands occurs in the great

Fig. 67.—Continental Plateau between Asia and Australia.

bends of the continental plateau; thus, almost one half (46%) occurs in the Arctic Ocean, and by far the largest part of this island area, including Greenland, Iceland, and Great Britain, occurs on the concave margin, or rim, of the plateau (see chart, pages 152, 153). More than one third (36%) of the continental island area occurs in the great bend of the Australian arm of the plateau, where it forms the Malay Archipelago (Fig. 67) and the continuous chain of islands along the concave margin of the bend, of which

Japan, the Philippines, and New Guinea are the principal groups. More than 3% of the continental island area occurs in the minor bends of the plateau occupied by the Caribbean and Mediterranean seas, the islands in the former locality occurring along the concave rim of the bend as the chains of the West Indies (see chart, pages 152, 153).

The remaining 15% of the continental island area embraces islands which occur along the margins, but are not confined to the concave margin of the plateau. About two fifths of this area compose islands lying close to the continents, and well within the limits of the plateau, as Newfoundland, Tasmania, and Ceylon, and the Alaskan and Chilean islands. The remaining three fifths compose the two groups of large islands—Madagascar and New Zealand. These are somewhat exceptional among continental islands, because they occupy outlying spurs, almost if not quite detached from the continental plateau, and because many of the forms of life on these islands differ from those of the adjacent continent. These islands are properly classed as continental islands, however, since their geological structure and some of their forms of life correspond to those of the adjacent continent, and because the water which separates them from the continent is shallow in comparison with that on the opposite or oceanic side of the islands.

Oceanic Islands.—About $\frac{7}{1000}$ths of the land on the globe occurs in numerous very small masses in the midst of the oceans and far from the continents. They occur in each of the three great oceans, but are most numerous in the tropical Pacific, where they lie in long, nearly straight, or gently curving lines extending in a general north-west and south-east direction. They contain none of the kinds of rock which compose the greater part of the great land masses, and, unlike all the continents and continental islands, they contain no native four-footed animals.

These islands are thought to be the tops of volcanic cones which have built themselves up from great depths by the solidification of successive outflows of melted rock or lava around some aperture in the earth's crust. They generally rise from the crest of the low sub-

Fig. 68.—Coral Formations.

marine ridges or plateaus which traverse the ocean basins, which accounts for the lineal arrangement of the oceanic island groups. The submarine ridges are probably formed in the same general manner as the continental plateau,—by differences in the temperature and density of adjacent regions of the earth's crust. These differences, however, are probably relatively slight, hence the submarine ridges do not stand so high as the continental plateau. Being larger, the Pacific contains a greater number of ridges than other oceans. The outflows of lava which largely compose oceanic islands, are

probably the direct result of the fracturings of the earth's crust and the heat generated by these movements of upheaval.

Coral Islands and Reefs.—In the shallow water about the shores of many oceanic islands, and in fact of all coasts where the water is warm and clear, low, rocky *reefs* frequently occur. These rise to about the level of low tide, and are composed of the peculiar coral limestone. Some oceanic islands rising from great depths seem to be composed entirely of this limestone. Such islands never rise more than 10 or 12 feet above sea-level, and usually take the form of a narrow strip or ring of rocky land, wholly or partially surrounding a shallow lake, or lagoon, of sea-water. These islands are called *atolls*, and are common in the warm parts of the Pacific and Indian oceans. Although apparently composed entirely of coral rock, it is probable that this rock merely covers and conceals a volcanic foundation at a comparatively slight depth.

Coral reefs and islands are composed of rock which is nearly pure carbonate of lime, and is remarkable in its manner of formation. Myriads of sea animals, called polyps, live in vast colonies on the bottom of clear, shallow, tropical seas. The skeletons of these animals are carbonate of lime extracted by the polyps from the sea-water. The general cross section of a polyp is shown in Fig. 69, the black portion indicating the stony skeleton. As the polyps grow upward, the lower part of their cylindrical skeleton becomes a solid stalk or stem of stone; from the sides of which other polyps grow outward, thus eventually forming an intricate network of stone branches. The surfaces of both this network and the parent stem may be covered with living polyps. Branches are constantly being broken off and ground into sand by the force of the waves, and this sand slowly fills up the spaces between the various stems and branches until the whole becomes cemented into solid coral reef rock. This also gradually grows by the same process, both upward to the surface of the water, and outward to a depth of about 20 fathoms, beyond which polyps on its surface can not live. If the water and bottom close to the shore are clean,

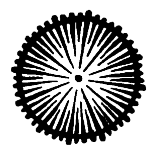


Fig. 69.

the reef extends quite to the shore, and is called a *fringing reef;* but if the water and bottom are muddy, a channel of water intervenes between the shore and the reef, and the latter is then called a *barrier reef.* Polyps thrive best in a heavy surf; hence, the outside of a barrier reef grows faster than the inside, which contains but few live polyps, and often does not grow as fast as it is dissolved away by the sea-water. Many islands of the Pacific are almost surrounded by a barrier reef, separated from the shore by a broad channel of water several fathoms deep. *Atolls* are much like such barrier reefs, except that they inclose no island. Since polyps thrive only to a depth of 20 fathoms, an atoll can be started only in shallow water. Rising as a reef to the surface in such a shallow place in the open ocean, it naturally assumes the irregular circular shape around a shallow lagoon, for the heavy surf favors the rapid growth of the outside edge, while the interior gradually dissolves away under the action of the sea-water. The size of the inclosed lagoon thus very gradually increases by the seaward growth of the encircling reef. Pieces broken from the outer edge of the reef and cast up by the waves gradually raise the reef above the surface of high tide, while wind and currents bring seeds which take root and cover the atoll with vegetation. Larger pieces, broken off by the waves, fall to the bottom and form a talus, or slope, of fragments of coral rock, on which the living surface portion of the atoll slowly advances into deep water.

Antarctic Lands.—In addition to the known land, an indefinite, but probably a comparatively small area of land is supposed to occur within the antarctic circle. Whether this land area is continuous, or whether it is broken up into an island group, is not known; but as the rocks found on the bottom of the southern oceans, and which have evidently been dropped by antarctic icebergs, resemble the rocks of the known continents and continental islands, it is inferred that the antarctic lands should be classed with them rather than with the oceanic islands.

CHAPTER XII.

THE SURFACE OF THE LAND.

Go up and view the country.—JOSHUA VII: 2.

Average Elevation.—The average elevation of the land on the globe is about 2,000 feet above sea-level. There is of course land much higher than this in each grand division; but if the entire land surface were reduced or increased to a uniform elevation, the resulting level surface would be about 2,000 feet above the sea.

GRAND DIVISION.	AVERAGE ELEVATION.	HIGHEST ELEVATION.	
Asia	2,884 feet.	Mount Everest,	29,002 feet.
Africa	1,975 "	Kilimanjaro,	20,065 "
North America	1,954 "	St. Elias Alps,	19,500 (?)
South America	1,764 "	Aconcagua,	23,910 "
Australia	1,189 "	Clarke,	7,256 "
Europe	958 "	Elbrooz,	18,493 "
Average of all land, 2,120 feet.			

Lowland and Highland.—Hence, in comparison with the land surface of the globe, any land whose surface lies at a less elevation than 2,000 feet may be considered as *lowland*, while all land at a greater elevation may be regarded as *highland*.

The Surface of both highland and lowland is uneven. It does not slope uniformly either in rate or in direction,

over any considerable area. In consequence of the diversity of slope, the surface of both lowlands and highlands is composed of a series of relatively high regions, separated from each other by a series of relatively low regions. These regions are of course high and low only in comparison with one another, for the low regions of the highlands have a greater elevation *above the sea* than the high regions of the lowlands.

Mountains and Hills.—A region is usually called a mountain in which the elevation of the surface changes about 1,000 feet or more by a slope rapid enough to be *plainly perceptible* to the eye. If the slope be perceptible, but the change of elevation be much less than 1,000 feet, the region is called a *hill*. A relatively high *point* from which the surface slopes perceptibly in all directions, is called a *peak*. A long but very narrow region from which the surface slopes downward mainly in two opposite directions, is called a *ridge* of mountain or hill. By far the greater number of mountains in the world occur in the form of ridges, or of ranges or chains; that is, a succession of closely adjacent ridges, whose lengths lie along the same general course. A relatively high region, composed of two or more roughly parallel mountain chains, separated by elevated land, constitutes a *mountain system*.

The dividing line between mountains and hills, based upon altitude alone, is purely arbitrary. Eminences called mountains in flat regions, would be called hills in regions where much higher eminences occur. A better plan would be to confine the term "hill" to relatively low eminences, composed of rock arranged in nearly horizontal layers.

Plateaus and Plains are extensive regions having a comparatively flat surface, or one whose *general* slope is so gradual as to be scarcely perceptible. Such regions are generally called *plains* in lowlands, and *plateaus* in highlands; but where the lowland rises imperceptibly into

highland, the apparently flat or gently undulating surface is called a plain in both regions.

This is the case with the Great Plains east of the Rocky Mountains, which slope imperceptibly downward to the east from an elevation of about 6,000 feet. On the other hand, relatively high, flat regions of the lowlands, when separated by steep slopes from lower regions, are frequently called plateaus; thus, the greater part of the Cumberland and Appalachian plateaus lies at a less elevation than 2,000 feet above the sea.

Valleys are usually understood to be long, V-shaped depressions, whose side slopes are very perceptibly steep, and whose bottoms have a much more gradual slope in the direction of the valley's length. Valleys occur in every region of the land, but are more numerous, deeper, and all their slopes are steeper in highland than in lowland regions, and among hills, mountains, and plateaus than on plains. Indeed, it is the great number of very deep and steep valleys which give to mountain regions their very rough and uneven contour.

The term valley is frequently used in a broader sense to include all the relatively low region lying between contiguous regions of highland. Thus, most of the United States between the Rocky and Appalachian mountains is said to lie in the Mississippi Valley. In this case the *general* slope of the sides of the valley is imperceptible, and is broken by steeper minor slopes into mountains, hills, plateaus, plains, and smaller valleys.

Steepness of Slopes.—All plainly perceptible slopes are generally supposed to be much steeper than they really are, while imperceptibly sloping surfaces of course seem level. The Great Plains east of the Rocky Mountains have an average slope of about seven feet to the mile. This is entirely imperceptible. Probably an inclination of between 200 and 300 feet to the mile is required before any slope can be detected in the absence of a level surface with which to compare it; such a slope makes an angle of about 3° with the horizontal. The great majority

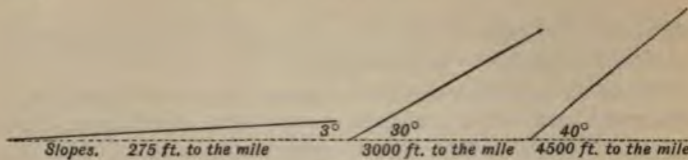
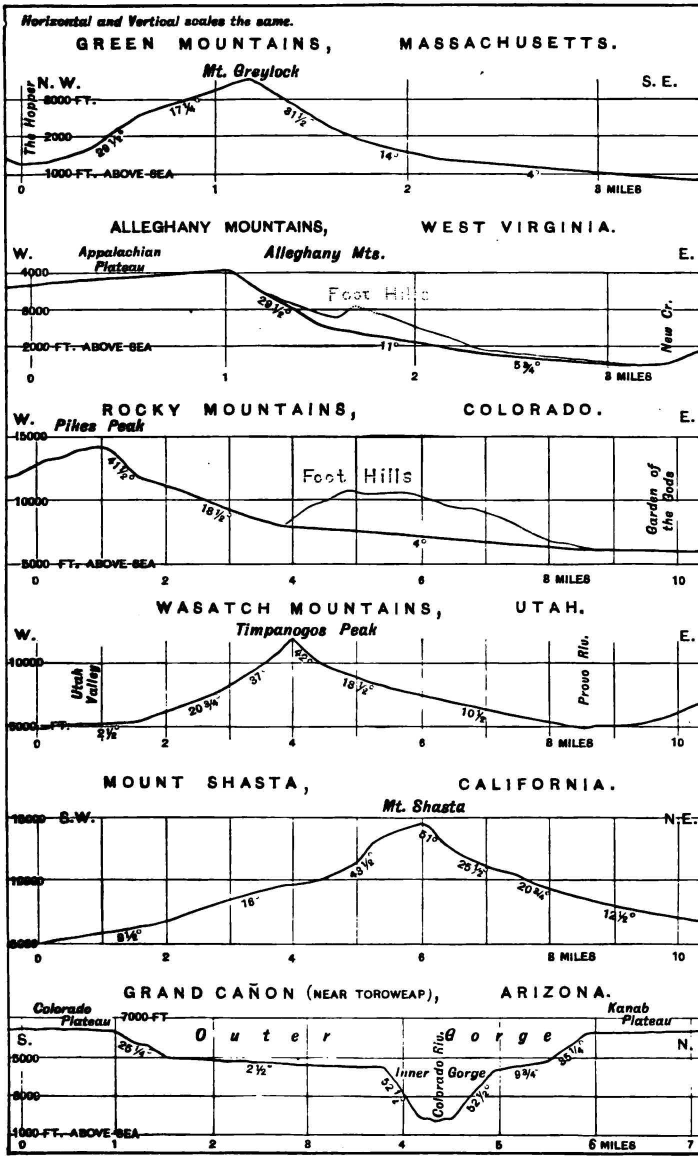


Fig. 70.

of *steep slopes* make an angle of less than 30° with the horizontal; that is, they rise at a rate of less than 3,000 feet to the mile, while slopes of 40° (4,500 feet to the mile) occur only in naked rock, and except when very short are exceedingly rare. Actual vertical precipices are never very high, for not only does a slope, or *talus*, tend to form against the bottom of the cliff by the accumulation of fragments detached from the top by the weather (Fig. 71), but the enormous weight of the overlying strata would crush the rocks forming the bottom of a very high cliff, and cause them to "creep" outward, thus reducing the lower vertical part of the cliff to a steep slope.

Fig. 71.—A Line of Cliffs, with Talus (Red Gate, Utah).

Some of the *steepest* general slopes in the United States are shown in the diagrams opposite. In nature they are broken by minor irregularities which render them for *very short distances* alternately steeper and flatter than represented, but the diagrams show the *average* or general slopes, and the height of these is seen to be in general



Profiles of Steep Slopes.

much less than the length. One general law is well illustrated by these diagrams: *almost all slopes of the land surface gradually become flatter as they are descended.* The reason for this will be explained later (page 220). The steepest *long* slope shown in the diagrams is that of the sides of the Grand Cañon of the Colorado River, where the surface falls about 3,000 feet in less than half a mile. This Cañon is often described as having nearly perpendicular sides. This is not the case, as is shown in the enlarged diagram (Fig. 72), which shows the profile of one side of the inner gorge of this cañon near Toroweap, where the slope, though not quite so long, is about as steep as at any other point. (P. 223.)

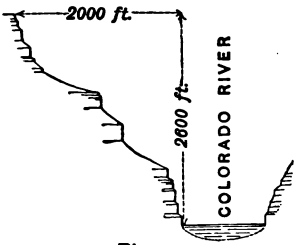
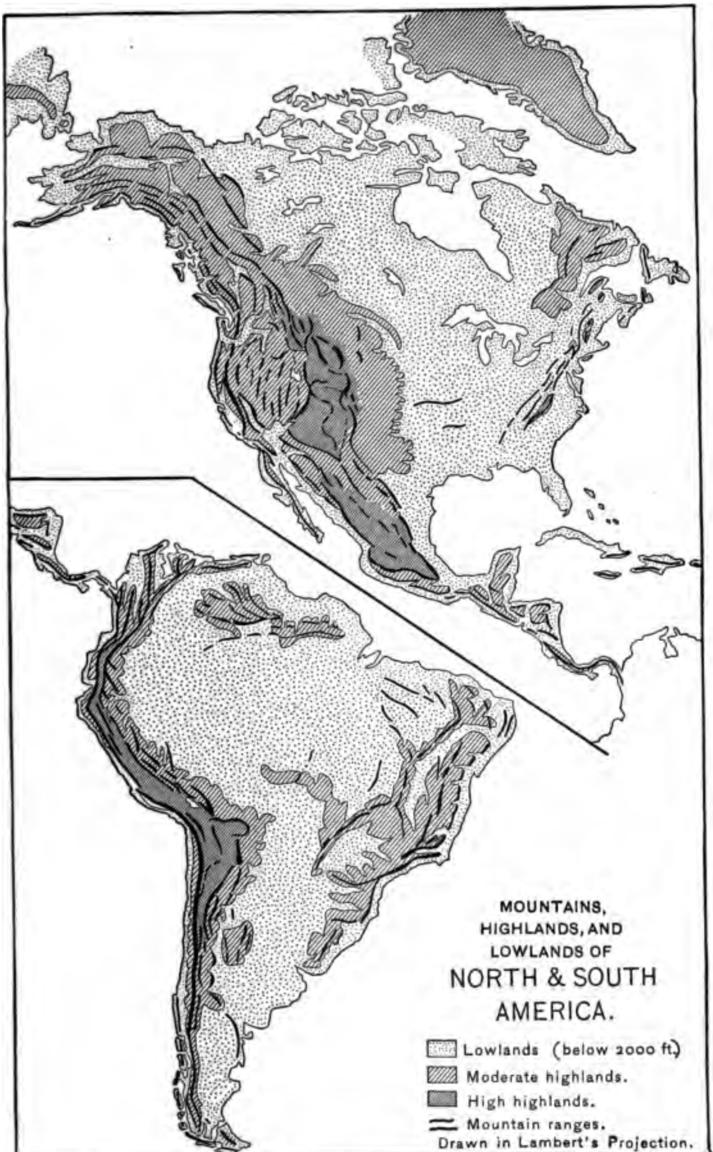


Fig. 72.

Highlands and Lowlands of North America.—North America contains two great mountain systems: the Appalachian system in the east, and the Cordillera system in the west. Each system is composed of numerous ranges or ridges, roughly parallel with each other and with the respective coasts of the grand division. The Cordillera is much the larger system in every way. It is bordered by two great chains, the Rocky Mountains on the east, and the Cascade Mountains, the Sierra Nevada, and the Sierra Madre of Mexico on the west. Between these are many isolated ranges. In each of these chains are many peaks between 12,000 and 15,000 feet high, while near Mt. St. Elias in the north are peaks over 19,000 feet high. In the south Orizaba rises over 18,000 feet above sea-level. These chains and the numerous shorter ranges and ridges between them rise from a rough plateau which maintains a general elevation of over 6,000 feet east of the Wasatch Mountains of Utah, but of less than 5,000 feet to the west of it. This relatively low portion of the plateau extending west and south-west from Great Salt Lake to the Sierra Nevada, is called the Great Basin.


MOUNTAINS,
HIGHLANDS, AND
LOWLANDS OF
NORTH & SOUTH
AMERICA.
Lowlands (below 2000 ft.)
Moderate highlands.
High highlands.
Mountain ranges.
Drawn in Lambert's Projection.

Toward the northern and southern extremities of the system active volcanoes occur, while in the western part of the central portion numerous volcanic cones and other evidences of recent volcanic action are found.

The Appalachian system throughout the southern portion of its extent consists of many sharp, parallel ranges or ridges rising from lowland elevations of less than 1,000 feet to a general elevation of between 2,000 and 3,000 feet above the sea. The general elevation of the

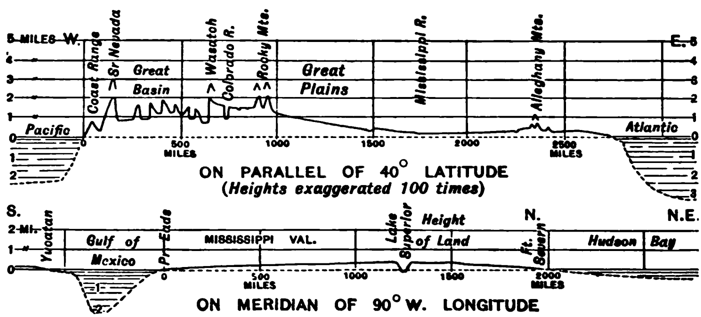


Fig. 73.—Two Sections Across North America.

eastern range is greater than that of the western ranges. Its highest peaks are Black Dome (6,700 feet) in North Carolina, and Mt. Washington (6,200 feet) in New Hampshire. From the summit of the western range the Appalachian "plateau," with an elevation of a little less than 2,000 feet, slopes westward, merging imperceptibly into the Mississippi Valley.

The portion of the Appalachian system lying north of the St. Lawrence River is called the Laurentide Mountains, and is very different from the southern portion of the system. It is virtually a low plateau having an elevation of about 2,000 feet, from which rise occasional more or less isolated peaks or short ridges, which are worn to a smooth and rounded outline; the height of these peaks is

generally less than 3,000 feet above the sea, though the highest is thought to exceed this elevation. Both the Appalachian and Laurentide mountains contain many evidences of very ancient, but none of recent volcanic action.

The Lowlands of North America lie chiefly between the two mountain systems, and extend from the Gulf of Mexico to Hudson Bay and the Arctic Ocean. Although broken by short slopes into valleys, local undulations, and hills, which, in the case of the Ozarks of Missouri, and the Wichitas of Oklahoma, are dignified by the name "mountains," still the general slope is entirely imperceptible, and rises from both north and south to a maximum elevation of about 1,800 feet in the Height of Land north of the Great Lakes.

South America contains three mountain systems: the Cordillera of the Andes, extending along the whole west coast, the Brazilian system in the east, and the Pacaraima system in the north.

The Cordillera of the Andes, though much narrower, is almost twice as high as the Cordillera system of North America. It consists in general of two main chains roughly parallel with each other and with the west coast, from which the surface rises by a very steep slope, the crest of the westerly chain lying in some places not more than 65 miles from the sea-shore, and bearing many peaks between 16,000 and 20,000 feet in elevation. Aconcagua, the highest peak, rises almost 24,000 feet above the sea. The eastern chain is not quite so high as the western; but near the central portion, where both chains are highest, it has several peaks of 20,000 feet and more. This system contains throughout its length many active or recently extinct volcanoes.

Between the central portion of the chains is a very high, broken plateau, whose elevation ranges from 12,000 to 14,000 feet. In the north, the eastern chain bears gradually off to the east parallel with

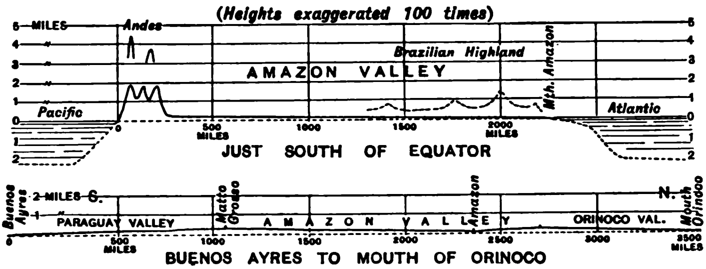


Fig. 74.—Two Sections across South America.

the Caribbean sea-coast, while the western chain, decreasing in altitude, bears to the north-west to form the highland connection, through the Isthmus of Panama, with the Cordillera system of North America.

The Brazilian and Pacaraima systems are much lower and less continuous than the Andes. The highest peaks are about 9,000 and 8,000 feet respectively, though peaks higher than 6,000 feet are extremely rare. The Brazilian system is composed of three, and the Pacaraima of two, chains roughly parallel with each other and with the nearest coast. The Brazilian system rises rather abruptly from a low and narrow coast plain, but the Pacaraima system and the landward side of the Brazilian system have their base on a highland which attains its elevation of about 2,000 feet by an entirely imperceptible ascent. The eastern highlands of South America, like those of North America, contain no vestiges of recent volcanic activity, but indications of ancient volcanism are found.

The Lowlands of the greater part of South America are exceedingly flat. The Amazon River, where it leaves the Andes, 2,000 miles from its mouth, is only 500 feet above the sea. In eastern Bolivia, where the western highland approaches the Brazilian highland most closely

the lowland between them is scarcely 1,000 feet above the sea, while west of the Pacaraima system the lowland has but half this elevation.

Euro-Asia, the largest grand division of the land, and the most irregular in shape, has the most extensive, the highest, and the most irregular mountain system, as well as the most extensive lowlands.

Mountains and Plateaus.—The highland region extends along the entire southern portion of the grand division from Portugal to Bering Strait, a distance of 10,000 miles. Though cut down to sea-level in one place—the outlet to Black Sea—this highland region, with its various plateaus and mountain ranges, may be regarded as a single vast mountain system. The general width and height of the system increase from either extremity toward the center, where the highland region is 2,500 miles broad, from north-west to south-east. The plateaus at either extremity of the system have an elevation of about 2,500 feet, which gradually increases to about 5,000 feet near the central region, where the surface abruptly rises to form the extensive Pamir-Thibet plateau, at an elevation of between 12,000 and 15,000 feet. This high plateau has a length of about 2,000 miles and an average width of 450 miles, an area equal to that of the United States east of the Mississippi. The broad plateaus of Asia are generally lower in the center than at the margins. Thus, the central parts of the Persian, East Turkistan, and Mongolian plateaus are 1,200, 2,200, and 3,000 feet respectively, while at the base of the surrounding mountains their elevation is about 5,000 feet.

Though when distant mountain ranges of Euro-Asia are compared, they vary greatly in the direction of their trend, yet when the system is viewed as a whole the various chains are seen to be roughly parallel with the axis of the highland region, with the south-

ern or eastern coast of the grand division, and with adjacent chains. Where the highlands are broad, the mountains generally rise from their northern and southern margins, inclosing the plateaus between. Several active volcanoes occur in this great mountain system, and many signs of recent volcanic action are found throughout its extent from Spain to Kamchatka. The gradual increase in the altitude of the mountains toward the central region of the highlands is as follows:

Spain,	*Long.*,	5° W. to 0°.	*Peaks*,	11,000 to 12,000 feet.
Switzerland,	"	8° E. to 15° E.	"	13,000 to 16,000 "
Caucasia and Persia,	"	42° E. to 50° E.	"	17,000 to 19,000 "
Pamir and Thibet,	"	70° E. to 90° E.	"	22,000 to 29,000 "
Thian Shan,	"	80° E.	"	21,000 feet.
Khin Gan,	"	105° E.	"	11,500 "
" "	"	117° E.	"	9,000 "
Stanovoi Mountains,	"	135° E.	"	4,000 "

Three wholly or partially detached regions of highland lie south or east of the main mass, being separated from it, however, by lowlands of small extent in comparison with the great lowland region to the north. These highlands constitute the plateaus of Arabia, India, and the coast region north of Corea. They have an average altitude of less than 2,500 feet, and are bordered by mountains of very moderate elevation. A mountain range, partially submerged, and roughly parallel with the east coast, forms the peninsula of Kamchatka and the chain of islands of which Japan, Formosa, the Philippines, and New Guinea are the largest. Through Borneo and Celebes this chain is connected with another more continuous chain, which, diverging from the east end of the Thibet plateau, forms the Malay peninsula and the islands of Sumatra, Java, and Timor. Most of these islands contain peaks of from 9,000 to 13,000 feet high, and very many of these are active volcanoes.

Lowlands.—The northern part of the grand division is a vast region of continuous lowland, having an extreme length of 10,000 miles, and a greatest width, in the longitude of the Caspian Sea, of about 2,500 miles. The lowest part of this region is covered by the Caspian Sea to a depth of 3,600 feet, but the surface of the sea is still 85 feet below sea-level. From this depression the surface

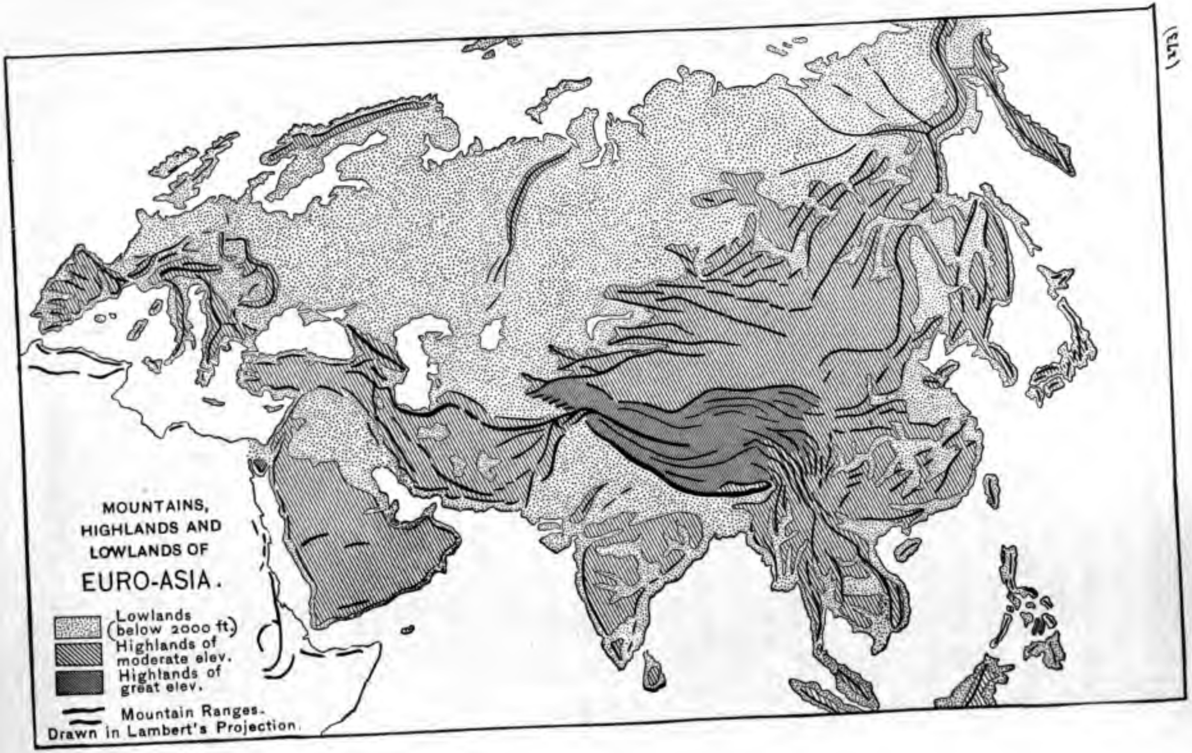
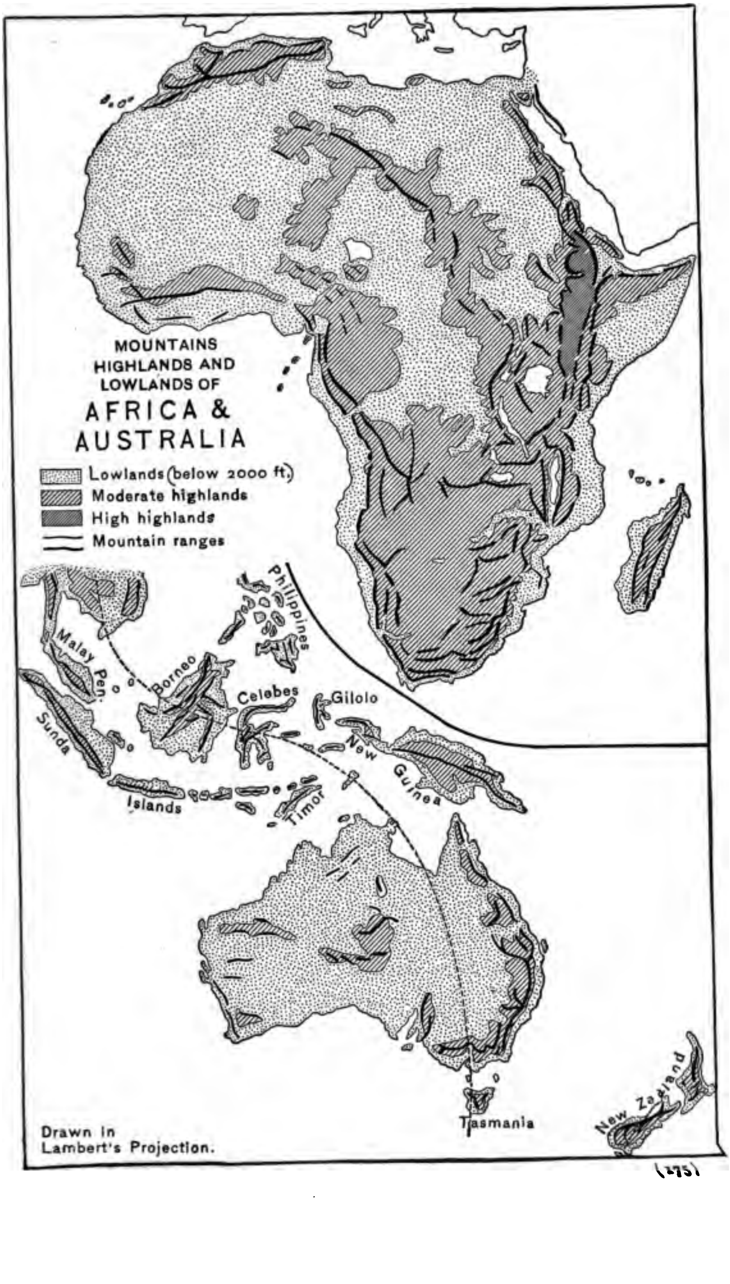

MOUNTAINS,
HIGHLANDS AND
LOWLANDS OF
EURO-ASIA.
Lowlands (below 2000 ft.)
Highlands of moderate elev.
Highlands of great elev.
Mountain Ranges.
Drawn in Lambert's Projection.

Fig. 75.—Two Sections across Euro-Asia.

rises to the north by imperceptible slopes to an elevation of about 1,000 feet, whence it imperceptibly descends to the north coast. These plains are called *steppes* in the south, and *tundras* in the north. This vast region rises in two places only, and then by almost imperceptible slopes, above the limit of lowlands (2,000 feet): (1) In the extreme north-west, to form the Scandinavian plateau, which falls off abruptly toward the sea from a general elevation of 2,000 to 4,000 feet, and bears some points over 8,000 feet high; and (2) between Europe and Asia to form the low Ural Mountains, whose highest points are about 5,500 feet. In the extreme east the lowlands are broken by several ranges of hills or low mountains putting out from the great system to the south. In both of these isolated highlands, vestiges of very ancient volcanic action are found.

Surface of Africa.—The main highland region extends along the eastern coast from the outlet of the Red Sea to the Cape of Good Hope. This highland increases in general width from north to south, and almost completely covers the southern portion of the grand division.

Three long tongues of highland extend to the north-west from the main mass until they gradually merge into the lowland. These tongues are separated from each



MOUNTAINS
HIGHLANDS AND
LOWLANDS OF
AFRICA &
AUSTRALIA
Lowlands (below 2000 ft.)
Moderate highlands
High highlands
Mountain ranges
Philippines
Malay Pen.
Borneo
Celebes
Gilolo
Sunda
Islands
Timor
New Guinea
Tasmania
New Zealand
Drawn in
Lambert's Projection.

(275)

other by two broad lowland valleys extending southward from the great lowland region which occupies northern Africa. One of these valleys is occupied by the Nile River, while the other contains the upper course of the Kongo, Lake Chad and its principal tributaries, and the upper course of the Niger. Minor elevations in the second valley have caused the lower course of the Kongo and Niger to bend at right angles with their upper course, and to cut narrow channels to the sea through the south-western highland tongue. A small, detached mass of highland in the extreme north-west extends parallel with the Mediterranean and Atlantic coast, and forms a continuation of the Italian region of elevation, which curves sharply back to westward through Sicily and the shallow extension from that island to Tunis (see page 152).

It will be observed that the main highland mass lies roughly parallel with the east coast, while the three tongues are roughly parallel with each other and with the north-east and south-west coasts of the grand division. Several active volcanoes and many indications of recent volcanic action are found in the eastern highland, while in the west but one active volcano occurs on the mainland, though evidences of ancient volcanism are numerous.

Heights.—The greatest heights of the grand division rise as more or less continuous mountain ranges from the margins of the highlands, and thus inclose a plateau whose general elevation is something less than 5,000 feet. The greatest heights occur along the eastern margin, peaks rising to nearly 15,000 feet in Abyssinia, and to 20,000 feet near the equator, where Kilimanjaro, the highest point in Africa, occurs. The peaks near the Zambezi sink to 7,000 or 8,000 feet, but rise again to 9,000 or 10,000 feet in the extreme south. Along the west coast the mountains are lower, their peaks rising from 5,000 feet near the Orange to 13,700 feet in the volcanic Cameroon Mountains at the head of the Gulf of Guinea, and

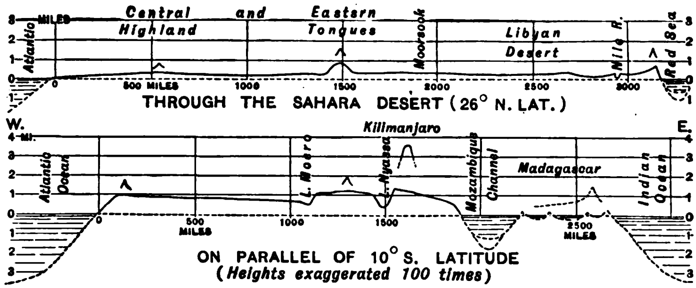


Fig. 76.—Two Sections across Africa.

thence sinking through the highland west of the Niger River to about 4,500 feet above sea-level.

The southern range of the Atlas Mountains in the north-west is nearly twice as high as the northern, and contains one peak of nearly 12,000 feet. The plateau between these ranges has an average elevation of about 3,000 feet. The highest peaks of the central tongue of highlands are about 8,000 feet, and of the north-eastern tongue about 7,000 feet. The main highland region is divided by mountain ranges into several basin-shaped plateaus. The highest, 6,000 to 7,000 feet, extends, with a width of 200 miles, from Abyssinia to the equator, a distance of 1,200 miles. South of this, the plateaus maintain an average height of about 3,500 feet, having a central elevation of about 2,500 feet, and a marginal altitude of about 4,500 feet.

The Sahara lowland has elevations of about 1,200 feet between the central tongue and the north-western highland, and on either side of the Lake Chad depression. Lake Chad is about 800 feet above the sea, while in the north, limited areas between Tunis and the Nile are depressed to about the level of the sea, being in some places as much as 167 feet below it.

Australia forms the extremity of a relatively small branch from the convex side of the main continental plateau; that is, Australia is connected with Asia by a system of narrow, complex wrinkles in the earth's crust,

whose crests in some localities do not rise quite to sea-level, though throughout the greater part of the distance between the continents the crests of the wrinkles protrude above the sea to form the long and generally narrow islands of the Malay Archipelago.

The axis of this whole region of elevations from Asia to Tasmania forms a sharply reversed curve. In the north the curve is concave toward the north-east, while in the south it is concave toward the south-west. The map (page 175) indicates that the law of the main continental plateau is equally true of this branch; namely, the land is more continuous and the plateau is higher on the convex than on the concave side of its axis; thus, in the north the Sunda Islands form a nearly continuous rim of land on the convex west side. They are separated from each other by narrow straits of relatively shallow water, and rise in many peaks to an elevation of 12,000 feet. They contain more active volcanoes than any other region of equal extent in the world. Gilolo and the Philippines, on the concave side, are much more discontinuous, are separated by very deep water, and contain peaks of only 5,000 to 8,500 feet. Volcanism, though active on this side, is less so than in the Sunda Islands. The southern part of the axis just reverses the high and low sides of the plateau. From New Guinea to Tasmania the eastern and convex side extends as an almost continuous region of highland, with peaks of 13,000 feet in New Guinea, and of over 7,000 feet in the Australian Alps; while on the concave side, the short west coast of Australia is the only land, and is quite low, rising in but two isolated instances to as much as 3,000 feet above the sea. In New Guinea and New Zealand there are active volcanoes; in Australia there are none, but signs of comparatively recent activity occur in the east, and of very ancient action in the west.

Transverse wrinkles cross the northern part of the axis to form the great islands of Borneo and Celebes, while across central Australia a broad transverse wrinkle or swell carries the surface gradually up to a general elevation of nearly 2,000 feet, and in places of over 4,000 feet above the sea. The south-east slope of Australia drops off rapidly to form the sea bottom at a depth of 15,000 feet, which then rises gradually to the crest of the sharply curved New Zealand wrinkle parallel with the Australian coast, and reaching in the volcanic peaks of those islands an altitude of 12,000 feet above the sea.

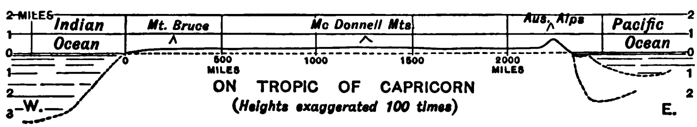


Fig. 77.—Section Across Australia.

Summary.—Thus, all the grand divisions contain mountain ranges, which are most numerous and highest on the side bordered by the nearly continuous highland rim; that is, on the west side of the New World, but the east and south-east sides of the Old World. Therefore, the great lowlands of the world border the Atlantic Ocean, from which they are separated either by no mountains or by comparatively isolated ranges of moderate elevation. Adjacent mountain ranges in all grand divisions are as a rule roughly parallel with each other and with the general trend of the nearest side of the continental plateau. Evidences of volcanic action are found in nearly all mountain regions. Present volcanic action or evidences of relatively recent action are most common toward that side of the grand division which constitutes part of the highland or convex margin of the continental plateau; while among the isolated highlands on the concave side of the continental plateau evidences of very ancient volcanic activity are most common.

CHAPTER XIII.

THE STRUCTURE OF THE LAND.

For a thousand years in thy sight are but as yesterday when it is past.—PSALM XC: 4.

Elements.—The earth has been examined to a depth entirely insignificant in comparison with its diameter, but so far as it has been examined, it appears to be composed mainly of twelve elements, or simple substances. These elements compose $\frac{99}{100}$ths of the earth's crust, and are: oxygen, silicon, aluminium, calcium, magnesium, potassium, sodium, carbon, hydrogen, sulphur, chlorine, and iron. The remaining $\frac{1}{100}$th of the earth's crust is composed of about sixty other elements. Among these rare elements are all the useful metals, excepting iron and aluminium.

Minerals.—With few exceptions, the twelve abundant elements do not occur in a free state, but in chemical combinations with each other and with the other elements. The stony substances resulting from such combinations are called *minerals*. The most abundant and common minerals are silica and its compounds. Next in abundance are the carbonates of lime and magnesia. The oxides of iron are almost as common, but not so abundant.

Rocks.—Most rocks are mixtures of two or more kinds of minerals, the particles of each being often visible to the naked eye. Thus, the granites are essentially mixtures of feldspar, quartz, and mica; ordinary "trap" rocks, or lava, of feldspar and pyroxene; sandstones consist mainly of particles of silica; limestones, of carbonate of lime;

and shales and slates, of silicates of alumina, the principal substance in clay. These grains are usually joined together by a cement of some mineral, which differs more or less from the mineral particles. Lime, which forms the essential principle of most artificial mortars and cements, is found in very many rocks as the natural cement binding together the particles, while peroxide of iron and silica serve this purpose in many other instances. The various colors of rocks, clays, and earths are very generally due to minute quantities of iron distributed through them in various combinations.

Soil.—All rocks disintegrate—that is, crumble to pieces—more or less rapidly when exposed to the weather; the process is therefore called *weathering*. In consequence, the surface of the solid rock over most of the earth is covered with a varying thickness of its own loosened and detached mineral particles. This loosened mass constitutes the *soil*. The surface soil is constantly being removed particle by particle—chiefly by the wash of rains to the nearest stream, but sometimes by winds as dust—while the rock beneath constantly breaks into soil. The disintegration and removal of the rock together constitute the process of *erosion*.

The chief agents in the disintegration of rocks by weathering are: solution, change of temperature, the beating of rain, gravity, vegetation, and winds.

(1) *Solution.*—Some rocks are completely dissolved by percolating water, but the majority are slowly broken up into particles by the solution of the cement which binds together the more insoluble grains.

(2) *Change of Temperature.*—The hardest rocks are cracked by the expansions and contractions accompanying sudden changes of temperature. The crevices thus begun are opened by repeated expansions of water freezing within them.

(3) *The beating of rain* overcomes the cohesion of the softer rocks, and assists solution and frost by detaching loosened particles.

Fig. 78.—Layers of Stratified Rock.

(4) *Gravity*.—When the base of a cliff is greatly eroded, the upper part breaks off and falls from its own weight.

(5) *Plants* often pry apart rocks by the growth of their roots, but their chief aid to disintegration is by increasing the solvent power of percolating water.

Classes of Rocks.—The solid rocks beneath the soil may be divided according to their structure or arrangement into two classes: *stratified* and *unstratified*.

Stratified Rocks include sandstones, limestones, and shales, and occur as a general rule nearest the surface of the earth. They compose the surface rocks of about nine tenths of the land. In some places their thickness is known to be very slight; in other places there is good reason to think that they extend to a depth of at least ten miles. The average thickness of stratified rocks over the land is probably between two and three miles.

Stratified Rock is characterized (1) by its arrangement in sheet-like layers, or *strata*, (Fig. 78), which vary from the thinness of a sheet of paper to a thickness of many feet. (2) By a more or less thorough assortment of the different minerals, and their collection into different strata; thus, in each stratum some one kind of mineral is usually greatly in excess of all other kinds. (3) By containing imprinted on their surfaces, or imbedded in their mass, traces of animals or plants which must have existed before the rock was formed. These traces of former life are called *fossils*. (4) By being largely composed of mineral particles whose irregular shapes indicate that they are merely fragments from some older rock mass.

These peculiarities can only be explained by supposing that these rocks resulted from the gradual compacting and hardening of beds of sand or mud, which had been deposited in water as sediment. Such beds of sediment are now forming in every body of quiet water, and are found of every degree of hardness and compactness, from that of the softest mud to that of the hardest rock. It is certain that at least most of the stratified rocks are of such origin. They are therefore called *sedimentary*, *aqueous*, or *fragmental* rocks.

Formation of Sedimentary Rocks.—The loose soil on the surface of the land affords directly or indirectly the greater part of the mineral particles which compose the sediment collecting on sea and

lake bottoms; hence, the disintegration of the rocks into soil is the first step in the formation of future rocks. Particles of sand, clay, and carbonate of lime predominate in most soils, but are all mixed together in endless confusion. Through the force of running water and of gravity the particles are assorted and eventually transported to some lake or to the sea, where they are deposited in more or less distinct beds. The material of pure sand (silica or quartz), owing to its hard and durable nature, disintegrates very slowly, and thus, speaking generally, forms the largest and heaviest fragments in sediment. The heaviest particles, of course, sink soonest; hence, sand predominates in the deposit nearest the shore, which gradually consolidates into sandstones of different varieties. The material of clay is derived from the chemical decomposition of feldspar, and is in very fine particles; hence, it does not sink so soon as the heavier particles of silica, but is carried to greater distances from the shore, where it predominates in the sediments and consolidates into various kinds of shale. Fragments of carbonate of lime are also carried down from the land, and are deposited according to their size and weight; but as this mineral is more or less soluble, these fragments grow smaller the longer they are in the water. Much carbonate of lime, therefore, reaches the sea *in solution*, and is generally distributed by ocean currents as a chemical ingredient of the water. From this ingredient aquatic plants and animals derive material for their shells and skeletons. Upon the death of the organisms, these sink toward the bottom as sediment. Life is so abundant in many parts of the sea that where the water is shallow these shell fragments accumulate on the bottom faster than the water can dissolve them. When this occurs in regions where but little sand or clay sediments are accumulating, beds of mud of nearly pure carbonate of lime may be formed, similar to, but not exactly like, the organic deep sea *oozes*. The consolidation of such beds produced by far the greater part of our limestones.

Unstratified Rocks underlie the stratified rocks and extend indefinitely into the interior of the earth. In some places the unstratified break through the stratified rocks, thus forming the surface rocks over about one tenth of the land. Unstratified rocks include the *granites*; the finer grained rocks, called *trap rocks*, as trachyte, basalt, and obsidian; and the still finer grained modern *lavas*.

Peculiarities.—The texture of unstratified rocks is peculiar in being either smooth and glassy, or, if granular, the grains or particles have more or less distinctly the regular shape and structure of the crystals peculiar to the mineral of which they are composed. Now, melted rock in cooling assumes this same glassy or crystalline texture, and this, with the absence of fossils, suggests that heat was an essential agent in the formation of the unstratified rocks. Hence, they are often called *igneous* (fire) rocks.

An igneous origin is also indicated by the manner in which unstratified rocks occur; namely, (1) as structureless and irregular shaped masses, forming the core of some mountain chains; (2) as lava "dikes," filling great fissures across the beds of the stratified rocks, as though lava had been forced into these fissures from below when in a melted state; and (3) as lavas, overlying stratified rocks, as though they had welled up through a volcanic vent or a fissure, and spread out over the surrounding surface before cooling.

Not infrequently dikes and sheets of unstratified rock are wholly composed of regular columns arranged side by side and closely fitting together. Now, the contraction of a bed of fine mud, as it dries in the sun, frequently causes cracks to traverse its surface in all directions, subdividing that surface into more or less regular shaped areas, which, as the cracks often penetrate deeply into the mud bed, are really but the ends of a series of columns similar to those found in the rock. Hence, the columnar structure of rocks is thought to have resulted from a similar cause, namely, the contraction of the rock mass in cooling.

Metamorphic Rocks.—Certain rocks, including slate, quartzite, marble, etc., possess more or less distinctly the stratified arrangement of the sedimentary rocks, with the crystalline texture of the igneous rocks. They are often of aqueous origin, but their original fragmental texture has subsequently been changed more or less

perfectly to a crystalline texture; they are therefore called changed, or *metamorphic*, rocks.

The causes of this change or metamorphism are heat, moisture, and pressure, while the change is greatly facilitated by the presence of certain common minerals. In order that the mineral molecules in a fragmental rock may assume a crystalline arrangement, a certain freedom of movement, as exists in pasty substances, is necessary. Under ordinary conditions it requires a temperature of nearly 3,000° to melt or liquefy rocks, but when thus melted, all stratification would disappear. When, however, rocks under great pressure are heated in the presence of even a very minute quantity of water so placed that it can not expand into steam, and especially if certain minerals are in solution in the water, the rock begins at temperatures of only between 200° and 300° to pass into a state which seems to allow of crystallization and of new chemical combinations, but does not destroy the stratification.

As the earth is penetrated, it becomes warmer at a rate which at a depth of 3½ miles would produce a temperature 300° above that at the surface. Now, in some places the stratified rocks are more than 3½ miles thick; it is therefore evident that the temperature of the bottom strata in such places must be at least 300° higher than when these bottom strata formed the surface of the deposit. As the weight of the sediment above would exert great pressure, and as all rocks contain more or less water percolating through them, which water, too, is frequently impregnated with just the necessary minerals, it is more than probable that even at this depth the conditions are generally favorable for the partial crystallization or metamorphism of the lower strata. As the thickness of the deposit increased by the continued accumulation of sediment on top, the heat, pressure, and metamorphism in the lower strata would increase, while the strata above would begin to crystallize, until finally the heat in the lower strata might become so great as to destroy all trace of stratification, and convert the rocks into true unstratified or igneous rocks. Since metamorphism takes place only at great depths, and since

metamorphic rocks could not have retained the stratified structure had they ever been rendered soft enough to admit of their being forced through the overlying rocks to the earth's surface, it follows that crystalline rock, having a stratified structure, occurs at the earth's surface only when it has been denuded, or laid bare, by the gradual disintegration and removal of a great thickness of rock which once covered it. The occurrence of metamorphic rock at the surface of the earth is thus of itself an indication of *extensive erosion*, or *denudation* (see Chapter XVIII).

The Primitive Rock, or that which first formed over the earth's surface by the gradual cooling of the molten globe, must have resembled the present igneous rock in containing no fossils, in being unstratified, and in having a crystalline or glassy texture. But nearly all crystals contain numberless microscopic cavities. In slags and lavas, which are known to have solidified slowly, like the primitive rock, from a melted state, these cavities are filled with the mineral of the crystals, but in a *glassy condition*. In crystals, however, which have been produced artificially by a process similar to that which resulted in metamorphism, many of the cavities contain nothing but *water*. Now, in most of the unstratified or igneous rocks, many of these crystal-cavities contain water, which indicates that they are aqueous rocks which have undergone complete metamorphism. In fact, it is probable that none of the primitive rock now remains on the earth's surface in its original position and condition, but that during the ages which have elapsed since its formation this rock afforded the mineral particles to soil and sediment, which eventually completely covered its surface, and through progressive changes became successively the stratified-fragmental, the metamorphic, and the unstratified-crystalline rocks which compose the present surface, and which are now supplying through similar processes these same particles to other similar cycles of change.

The Land was once Submerged.—Since most, if not all, of the rocks of the land are thus but more or less completely changed sediments, it follows that the present land must at some time have been entirely under water in order that the sediment might accumulate. All of the land could not have been under water at one time, however, for it has been seen that the bulk of the sediment comes from the disintegration of an adjacent land surface. Hence, we conclude that adjacent areas of the land have alternately been depressed below and then elevated above the surface of the sea—perhaps many times—the area above the sea supplying the material which was deposited on the adjacent depressed area, which, when subsequently elevated, supplied material for the sediment collecting in surrounding depressed regions.

This makes it evident that no stratum of sedimentary rock is continuous over very wide regions, but that each, considered as a whole, is a great cake, whose thickness decreases gradually in all directions from the region which, at the time of its deposit, was nearest to the source of supply, and hence received the most sediment.

Disturbed and Faulted Strata.—That such movements of elevation and depression are possible, is proved by the fact that in many localities the coast regions of the land are observed to be very gradually rising above or sinking beneath the adjacent water surface, while such movements are proved to have taken place in regions far from the present coasts by the position of the strata. Sediment will not rest at all on a steeply sloping bottom, and its deposition tends to lessen gentle slopes. It is therefore certain that most of the sedimentary strata were originally nearly or quite horizontal. As actually found, however, the strata are seldom exactly level; they every-where show more or less distinctly traces of tilting or curvature, as

though they had been thrown from their original horizontal position into a series of great, wave-like undulations. The surface at the crest and trough of such a rock wave was of course elevated and depressed respectively when the movement took place. In some places the waves are short and high, in which case the strata composing their sides slope, or *dip*, at a steep angle; in other cases, the waves are so long and flat that the dip of the strata is imperceptible. Frequently the strata are found to be broken

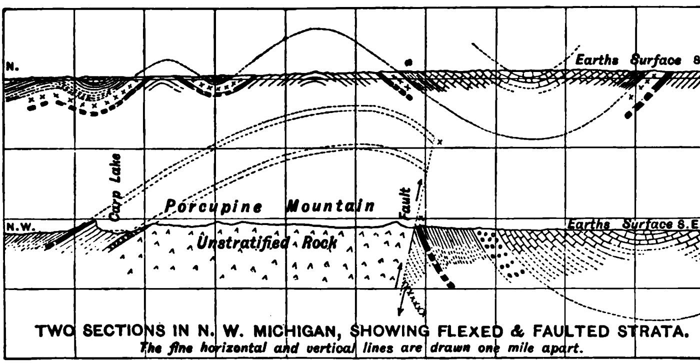


Fig. 79.

across, and the strata on one side of the break to have been upheaved above or depressed below the corresponding strata on the other side. This is called a *fault.*

It seldom happens that the strata can be actually seen continuously from the crest to the trough of a wave; they generally dip down out of sight into the earth in one direction, while the top of the wave has been carried away piecemeal by erosion, leaving only the ragged edges of the strata to compose the earth's surface. The shape of the wave, however (shown by the dotted lines in the diagram, Fig. 79), is indicated by the various dips of the adjacent strata. Erosion has in the same manner quite generally carried away the upheaved side of faults, so that their position is indicated by a sudden change in the character of the rock rather than by a sudden

change in elevation in the earth's surface. Many circumstances, such as the enormous erosion, prove that these faults and flexures of the strata were not produced by great single movements, but that each is the aggregate result of thousands of slight movements of a few inches or a few feet, occurring at irregular but very long intervals of time. These slight movements are still taking place in all parts of the world, and are, as we shall see later, the cause of earthquakes. There is probably no locality in which these movements are always in the same direction, either upward or downward; but, *in general*, the convex or Pacific side of the continental plateau seems to be slowly rising, while, with certain local exceptions, the concave or Atlantic side seems to be gradually sinking.

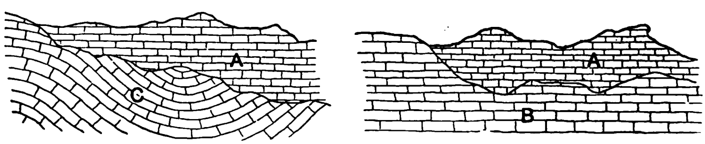


Fig. 80.—Unconformable Strata.

Unconformity of the Strata.—In some places a series of strata *A* (Fig. 80), having a certain dip, rest directly upon the *eroded surface* of another series, having either the same dip (*B*), or an entirely different one (*C*). The two series are then said to be *unconformable.*

Such a position indicates several movements of the earth's crust; thus, (1) an upward movement of the sediments *B* or *C* to bring them above the water that they might be exposed to the weather and eroded; (2) a downward movement to allow the deposit of the sedimentary rock *A* beneath the water, and (3) an upward movement to convert this deposit into the present land.

Relative Age of Rocks.—When the *relative* position of rocks has not been greatly disturbed by subsequent movement, it indicates the order of formation or *relative age* of the rocks, the highest being the youngest and the lowest the oldest. But this method involves the direct comparison of the position of rocks, and therefore applies

only to rocks in the immediate neighborhood of each other. To determine the relative age of the rocks composing widely separated regions—on different continents, for instance, or on opposite sides of the same continent—some other method has to be used, since it is never possible to trace the strata from one region directly to the other over the intervening distance. The only known method for identifying the relative periods in geological time, at which rocks in widely separated regions were formed, is by a comparison of their fossils.

Fig. 81.—Rock Fragments, showing Embedded Fossils.

Fossils.—The harder parts of land or aquatic animals and plants are sometimes buried in adjacent accumulations of sediment and preserved for long ages. When at last they decay, a hollow mold having their shape or outline is left in the hardened deposit, and is gradually filled up solid by the precipitation of some mineral in solution in the water percolating through the deposit. Thus a fragmentary record of the forms of life which existed at the time each layer of sediment was deposited is preserved within the rock stratum, either as the organic remains itself, its empty mold, or as a stone cast (Fig. 81) filling up this mold, until metamorphism effaces, more or less completely, both the lines of stratification and the fossil contents of the rocks.

Sometimes the precipitation from the percolating water replaces the organism particle for particle as it decays, thus preserving in stone all the delicate internal structure of the organism. Such fossils are called *petrifactions*. In other cases, only a portion of the substances liberated by the decay of the organism escapes, and the residue recombines into a new substance which may or may not retain the outline of the organism. Coal, asphalt, petroleum, and "natural gas" are the new substances which, under different circumstances, result from this process (page 369).

Identification of Relative Age of Strata by Fossils.—Careful examination of the fossils in thick series of stratified rocks, whose relative age is indicated by the relative position of the strata, reveals that the fossils at the bottom are not quite the same as those at the top of the series. As the series is ascended, different kinds of fossils gradually disappear, while other kinds gradually make their appearance, and are in turn replaced by newer forms. It thus appears that each stratum contains a few kinds of fossils not found in any other strata. These peculiar fossils, though not always the most numerous, are called the *type fossils* of that stratum. When similar type fossils are found in widely separated regions, they always succeed each other in the same general order; that is, the older fossils in one region are also the older in other regions. It has thus been established that the gradual changes in the forms of life in the past have taken place in the same general order all over the world, and that similarity of type fossils serves to identify corresponding strata in widely separated regions, and to afford a clue to the relative ages of rocks.

It is probable that these changes in life forms took place more rapidly in some regions than in others; hence, the occurrence of similar type fossils in widely separated regions does not necessarily indicate that these organisms lived at *exactly* the same time, but that they lived when the changes of life forms had reached corresponding periods in the two regions.

Classification of Rocks.—The rocks which expose their edges at some point or other of the earth's surface are classified according to their relative age. The thousands of strata are divided into five great *groups*, each of which marks an *era* of time: (1) Azoic (lifeless) or Eozoic (dawn of life), the oldest, in which all the strata yet found are so completely metamorphosed that the fossils are either effaced entirely or rendered unrecognizable; (2) Paleozoic (ancient life), or Primary, in which most of the strata have been metamorphosed, but some retain their fossils as the most ancient recognizable forms of life; (3) Mesozoic (middle life), or Secondary, in which metamorphosed strata are frequent; (4) Cainozoic (recent life), or Tertiary, in which metamorphism is quite exceptional; and (5) Post Tertiary, or Quaternary, which includes fossils of the present forms of life, and in which no metamorphosed strata are found. The strata composing these groups are subdivided into *systems*, each marking a *period* of time; these into *series*, marking *epochs* of time; and these again into *stages*, marking *ages* of time; while the stages are composed of *beds* or individual strata.

Eras of Time.	Periods of Time.
Quaternary.	Recent Pleistocene.
Tertiary or Cainozoic.	Pliocene. Miocene. Eocene.
Secondary or Mesozoic.	Cretaceous. Jurassic. Triassic.
Primary or Paleozoic.	Permian. Carboniferous. Devonian. Silurian. Cambrian. Archæan.
Azoic or Eozoic.	*Not subdivided, because as all stratification and fossils have been destroyed by metamorphosis, nothing remains to determine the relative ages of different parts of the group.*

Geological Time.—If any of the numerous changes in the past which are indicated by the study of the rocks be compared with the rate at which similar changes are taking place in the present, the

conclusion is irresistible that geological time must be very, very long. If only the small thickness of sediment deposited in one year by even the muddiest water be compared with the very great average thickness of the sedimentary rocks, one becomes convinced that many thousands or even millions of years have been required for these rocks to accumulate. There is no way to determine the exact length of geological time. Some circumstances indicate that at least 100,000,000 years must have elapsed since the oldest known sedimentary rocks were deposited; other circumstances indicate that it could not have been more than 3,000,000 years; but neither of these estimates is accurate—the time may be greater, or it may be less. All that can safely be affirmed is that the fragmentary record of the earth's history which the sedimentary rocks afford, covers a very long period of time.

It is perhaps impossible for the human intellect to grasp the lapse of time comprehended in the expression "one million years." By a great effort of memory, an old man may appreciate the length of not much more than half a century; and yet if half a century be represented by a distance of three inches, a million years would be represented by one mile.

CHAPTER XIV.

THE WATER OF THE LAND—SPRINGS.

He sendeth the springs into the valleys, which run among the hills. They give drink to every beast of the field.—PSALM CIV: 10, 11.

The vapor of the atmosphere, through its condensation into rain, snow, dew, etc., supplies all the water encountered on the surface of the land. This may be classified according to its manner of occurrence, as *springs*, *streams*, *glaciers*, and *lakes*.

Permeability of Rocks.—All rocks can absorb more or less water. Clay and fine grained, compact rocks, though they may contain water, do not allow it to escape readily, and are therefore said to be *impermeable*. A layer of soil, sand, or coarse grained, loosely cohering, or much fissured rock, on the contrary, allows water to pass through it copiously, or is said to be *permeable*.

Invisible cavities between the mineral particles, and visible fissures make up from one sixtieth to one half the bulk of most rocks. Water is absorbed or forced into these cavities by its own weight (gravity) and by capillary attraction (adhesion). When the cavities are very minute, capillary attraction is stronger than gravity, and holds the water fast in the cavities, making the rock impermeable though it contains water. When the cavities are large, gravity is stronger than capillary attraction, and the water sinks through the cavities and escapes from the rock below.

Surface Springs and Wells.—When the surface rocks are permeable, a large part of the rain or snow water sinks through them until it reaches and saturates an impermeable stratum. Being unable to escape through this

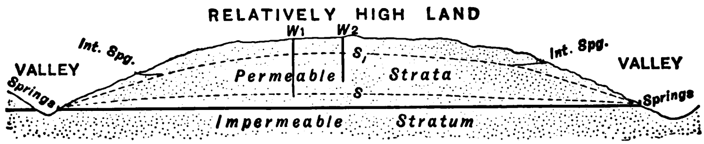


Fig. 82.

stratum, the water accumulates in and saturates the overlying rocks to a height (*s*, Fig. 82) where its own pressure forces it to move slowly along the depressions in the surface of the impermeable stratum. If this stratum is at such a slight depth that its edges crop out on the sides or in the bottom of the adjacent valleys, the water issues along this line of outcrop as *surface springs*. During wet weather the water collects in the rocks above the impermeable stratum faster than it escapes at the springs; the upper limit of saturation (*s*) therefore rises, its elevation being approximately marked by the surface of the water in wells. During dry weather the continued flow of the springs causes the limit of saturation to fall. If it should fall below the line *s* all the springs would dry up, although a well (*w*1) penetrating below this line would still supply water, while a shallower well (*w*2) would be dry. When the limit of saturation is very high (as *s*1), the increased pressure frequently forces the water to the surface at unusually high levels, forming wet weather or *intermittent springs*, which flow only until the excessive pressure is relieved by the lowering of the limit of saturation.

Deep-seated Springs and Artesian Wells.—When inclined strata outcrop at the earth's surface, and are arranged in such a manner that permeable strata are inclosed between impermeable strata, the rain or snow water which sinks into the permeable strata at their outcrop is confined in these strata by the impermeable beds above and below. To whatever depths the permeable beds may

descend, this water necessarily follows, and may in this way travel underground for many miles and reach depths of thousands of feet, until stopped by the gradual thinning out of the stratum, by its sudden ending in a close fault, or by the high temperature of the earth at extreme depths. When the descent of the water is stopped from any cause, the strata gradually become saturated up to the lowest level of their outcrop. The water in the saturated strata toward the lower end of the incline is of course pressed upon by the weight of the water toward the upper end. This pressure is often great enough to

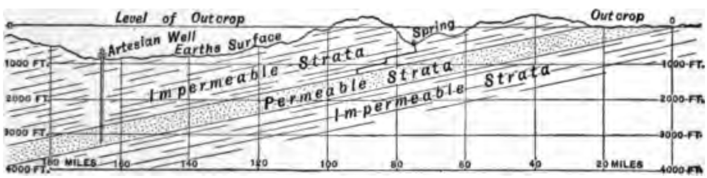


Fig. 83.

force the water to clear a passage for itself through some small fissure or other channel in the overlying impermeable beds, and, rising in this channel, to gush forth as a deep seated spring or natural fountain in a region where the surface is at a *lower level than the surface region where the permeable beds receive their supply of water.* An *artificial* channel of this kind, produced by drilling a hole through the impermeable strata, constitutes an *artesian* well, so called from its early use in Artois, France.

Theoretically, the water will rise through the well to the same height as the outcrop of the permeable strata; but the obstruction offered to the flow of water by the permeable rock and the leakage through the confining strata considerably reduces the height to which the water will rise. Where these two factors are very small, the water has been found to rise *to the surface* when the surface at the well is about as many feet below the surface at the outcrop, as the

two localities are distant from each other in miles. If this difference in height is much greater, the water may rise from the well into the air as a jet or fountain. Artesian wells are now very common—almost every city in America and Europe containing one or more. They are especially valuable in regions having a dry climate, as in the western portion of the Union and the desert portion of Algeria. These wells vary greatly in depth in different localities: one in Berlin is 4,172 feet deep; one in St. Louis, Mo., is 3,843 feet; in Budapest, Hungary, over 3,000 feet; in Cincinnati, O., 2,408 feet; in Louisville, Ky., 2,086 feet.

Use of Springs.—By absorbing and temporarily retaining a large part of the rainfall, the permeable rocks prevent devastating floods which otherwise would accompany every heavy rain, while by the *gradual* surrender of the absorbed water in springs the supply of fresh water at the earth's surface is maintained through ordinary seasons of drought.

Devastating floods sometimes occur, it is true, but are almost invariably due to the rapid melting of snow by warm rains at a time when the underlying soil is either completely saturated or is rendered temporarily impermeable by frost. In ordinary summer droughts, such streams as the Ohio and upper Mississippi, which are not supplied at that season by melting snows, contain only spring water. Should the drought continue long enough, the springs would exhaust the underground supply, and such streams would dry up.

The temperature of the water in springs is nearly constant throughout the year. It frequently seems warm in winter and cool in summer, but it is really the temperature of the air and surface rock which varies—the spring water seeming warm or cool in comparison. The temperature of different springs, however, varies greatly. It is rarely less than 40° Fahrenheit, but may range upward to the boiling point. When the temperature of the water is much higher than the mean temperature of the surface rocks in the vicinity, the spring is called a warm or *thermal* spring. Springs slightly warmer than the surface rocks are common, and springs much warmer are by no means rare.

Artesian Well at Prairie du Chien, Wis.

In the region of volcanic rocks between the Rocky Mountains and Sierra Nevada, perceptibly warm springs are the rule. East of the Rocky Mountains they are more exceptional, but are found in nearly every state;—a very few are named below:

Name.	Locality.	Temp. of Spring	Mean Temp. Surf.	Excess.	Flow Gal. per Hour.
Lebanon Springs,	Columbia Co., N. Y.	75°	46°	29°	30,000
Warm "	Bath Co., Va.	98	46	52	360,000
Sweet "	Monroe Co., W. Va.	79	46	33	48,000
Warm "	Meriwether Co., Ga.	90	60	30	84,000
Hot "	Garland Co., Ark.	157	62	95	20,100
Palmyra "	Jefferson Co., Wis.	72	46	26	———
Blankenships "	Texas Co., Mo.	75	57	18	2,000

Spring water derives its temperature from the rocks through which it percolates, and the rocks at a very slight depth cease to be affected by the daily and seasonal variations of surface temperature. Since the rocks in non-volcanic regions become warmer at an average rate of 1° for each 50 feet of increased depth, and since the water percolates very slowly, it has time to acquire the rock temperature during its downward passage. It follows more or less open channels in its journey upward or outward to springs, and flowing more rapidly does not lose all of its acquired heat. In non-volcanic districts the excess of temperature of spring water affords a very rough approximation of the depth from which it has come. The Arkansas Hot Springs have an excess of 95°, and must come from a depth of nearly a mile. The water of deep artesian wells is almost always perceptibly warm: that at St. Louis has a temperature of 105°, and that at Louisville of 76½°, the mean temperature of the air at those places being 55° and 57° respectively.

Spring Water.—In percolating through the rocks, the water is constantly dissolving and carrying along with it soluble minerals. In addition to this, it is constantly causing chemical changes, by which new and soluble substances may be made from insoluble minerals. Frequently these new substances are gases, with which the water is charged when it arrives at the surface. The most common gas

thus produced is carbonic acid, which, escaping in minute bubbles, causes the usual "sparkle" of spring water. The gas sulphuretted hydrogen causes the disagreeable odor of most "sulphur" springs. Thus, strictly speaking, all springs are mineral springs, but only those are usually so called in which the mineral or gaseous contents impart a perceptible taste or peculiar medicinal quality to the water.

The minerals which most commonly occur in spring water are:

Carbonate of lime " " magnesia	making temporary hard water.
" " iron,	" chalybeate water.
Sulphate of lime (*gypsum*), " " magnesia (*Epsom salt*)	" permanent hard water.
Chloride of sodium (*common salt*),	" saline water.
Nitrate of potassium (*saltpeter*), Sulphate of sodium (*Glauber salt*), Bicarbonate of sodium (*common soda*), Sulphate of alumina with the Sulphate potassium or sodium (*alum*)	making alkaline water.
Silica, making silicious water.	

It is the relatively large or small quantity of lime or magnesia contained in the water which renders it hard or soft. Soap produces lather in soft water; in hard water it does not. If these minerals are present as carbonates, they may be removed from solution by boiling; if they are sulphates, the water is permanently hard.

Caverns, Sink-holes, and Spring Lakes.—Caverns, or subterranean tunnels and chambers, are formed by the prolonged solution and abstraction of mineral matter by percolating water. In some limestone districts, owing to the solubility of this rock, such caverns are often many miles in extent. Mammoth Cave, in Kentucky, and the Luray Caverns of Virginia are noted instances. By the falling in of the roofs of caverns, or by the solution of the rock along the vertical joints that serve as channels for descending rain-water, sink-holes are formed—such as occur

in the blue grass region of Kentucky. The surface drainage, creeks, and even large streams may disappear in sinkholes directly underground, where they greatly hasten the work of cave formation. The falling of the roof of a cavern, by obstructing an underground stream, might cause the water to rise through the débris and form a *lake in the sink-hole.* The enormous springs of Florida, as Silver Spring and Orange Spring, into which steamboats can ascend, as well as many large spring basins in other limestone regions, were probably formed in this manner.

Since mineral matter in solution does not impair the clearness of spring water, the amount abstracted from the rocks is seldom appreciated. Average spring water contains more than $\frac{2}{10000}$ths of its weight of dissolved mineral matter. The springs of the United States east of the Mississippi are almost innumerable, but the discharge of water from only 900 of them has been measured: these collectively bring to the surface *each year* a quantity of the underground rock equal to a mass 10 feet square and two miles long.

Deposits of Springs and Percolating Waters.— The power of water to dissolve most minerals increases with its temperature and the amount of gases it contains. Percolating water at great depths, therefore, generally dissolves more mineral matter than it can hold in solution when it reaches the surface, where it cools, and, being relieved of pressure, much of its carbonic acid gas escapes to the atmosphere or is absorbed by aquatic plants or mosses. Hence, deep-seated springs are usually surrounded by a deposit of the minerals with which the water is impregnated. Sometimes this deposit may even form large hills; sometimes it forms a mound around the spring, over the sides of which the water falls, while the spray, evaporating from surrounding objects, leaves them also incrusted with a mineral deposit. Percolating water evaporating on the sides and roof of limestone caverns, leaves the walls incrusted with carbonate of lime in beau-

Fig. 84.—Scenes in Mammoth Cave, Ky.

tiful masses of crystals. Water slowly evaporating as it drips from the roof of caverns to the floor beneath leaves a deposit on both places, which gradually grows downward from the roof as a *stalactite*, and upward from the floor as a *stalagmite*, until these meet and form one continuous column of stone.

The deposit of calcareous springs, or travertine, may be white, or, if iron is also present in the water, it may be yellow, brown, reddish, or beautifully striped. Chalybeate or iron spring deposits vary from bright yellow to brown. Sulphur is frequently deposited by springs impregnated with sulphuretted hydrogen, and white siliceous sinter, by hot springs in volcanic districts.

Land-slips.—Absorbed water lessens the cohesion of most rocks; it renders impermeable clay more or less plastic and slippery, and tends to soften many permeable limestones and sandstones. When saturated, rocks at some depth below sloping surfaces may thus allow the overlying rocks to slide downward under the pressure of their own weight, especially when that is increased by the weight of an unusually large quantity of percolating water during wet weather. Such movements are called *land-slips* (page 261).

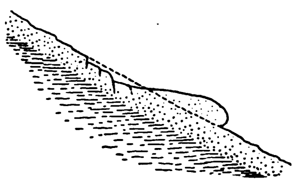


Fig. 85.

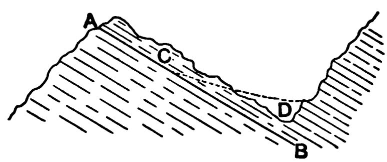


Fig. 86.

Small land-slips (Fig. 85) in which the soil and subsoil to a depth of a few feet slip a short distance downward, are common on all hill-sides, especially where the subsoil is underlaid by strata of clay, as is the case in the vicinity of Cincinnati. Large land-slips are generally confined to hilly or mountainous regions, where the strata are inclined at nearly the same angle as the surface. In such localities serious land-slips are not uncommon. Some stratum, as *AB* (Fig. 86), has its cohesion weakened by moisture until it is not able to support the weight of the overlying mass *C*, which suddenly starts downward, carrying with it the forests, houses, and every thing on its surface. The mass overwhelms whatever it meets, and may form a natural embankment across the valley at *D*. By obstructing the flow of the drainage, such an embankment may cause the formation of a more or less permanent lake on its upper side. Many mountain lakes have thus been formed by land-slips.

CHAPTER XV.

STREAMS.

Then the channels of water appeared, and the foundations of the world were laid bare.—PSALM XVIII: 15.

Streams are bodies of water flowing in definite channels from a higher to a lower level over the earth's surface. The water in streams is the excess of the rain-fall on the land over evaporation. Streams are called rills, brooks, creeks, and rivers as they increase in relative size.

Sources and Mouth.—The beginning of a stream, at the higher level, is called its *source.* The source of a stream is generally a spring, which, it has been seen, is but the re-appearance of absorbed rain-fall; but the source may be a mass of melting ice or snow, a lake, a swamp or marsh, or simply the water of a shower that flows over the surface after the soil is completely saturated. The place where a stream joins or flows into a larger stream, a lake, or the sea, is called its *mouth.*

General Law of Streams.—Water, when free to move under gravity, always flows to the lowest attainable level and by the steepest path it can find. Therefore, *streams always occupy lines of depression, or valleys.* Hence, streams generally increase in size as they advance in consequence of the constant addition of water from the sides of the valley. This water collects in the depressions in the valley sides, down which it flows as minor streams or *tributaries* to the main stream in the bottom of the valley.

(193)

Thus, the Ohio and Arkansas rivers drain parts of the valley sides, and are tributaries to the great Mississippi; the Wabash, Miami, and Licking rivers perform the same office in the smaller Ohio valley, and are tributaries to that river; the Whitewater and Mad rivers are similarly tributaries to the Great Miami; and so on down to the smallest streams, whose tributaries are mere threads of water, hidden, perhaps, under the grass or fallen leaves.

Stream Systems and Drainage Basins.—A stream, and all the lesser streams that contribute water to it, constitute collectively a stream system. The whole surface of the land whose inclination is such that it contributes water in time of wet weather to any stream of a system is called the *drainage basin*, or simply *the basin* of the main stream of that system.

Water-shed.—The boundary line of a drainage basin is called the *water-shed*, the *water parting*, or simply *the divide*, between that and adjacent basins. The location of water-sheds is exactly the reverse of that of streams; they always occupy lines of elevation. The crest of every sharp ridge forms a water-shed, but the top of an imperceptible swell in an apparently level prairie is also a true water-shed. Hence, a water-shed may be defined as the irregular line of *relatively* high land formed by the meeting of opposing slopes, whether the slopes are long or short, flat or steep.

The chart (Fig. 87) shows the main water-shed, the drainage basin, and the principal streams constituting the system of the Mississippi River. In the west and east respectively the water-shed generally follows the lofty crests of different ridges of the Rocky and Appalachian mountain systems, but in each locality it sometimes crosses from one ridge to another, following the highest part of the intervening valley. In crossing from one mountain system to the other, the water-shed follows the line which is *continuously* the highest across the intervening low country. Near the head of Lake Michigan this great water-shed, which divides the drainage of nearly the whole grand division, lies in the apparently level prairies scarcely

Fig. 87.

600 feet above the sea. Each stream of a great river system has a minor stream system, basin, and water-shed of its own.

Oceanic and Inland Drainage Basins.—The almost continuous highland region that lies near the convex margin of the continental plateau forms the main water-shed of the land. Thence, the surface descends by long and gentle slopes toward the Atlantic and its great arms, but by comparatively short and steep slopes toward the Pacific and Indian oceans. These slopes embrace the drainage, or *hydrographic*, basins of the respective oceans. There are areas in each grand division where the rain-fall is so slight in comparison with the evaporating power of the air that all the streams are entirely evaporated before they can traverse the region. These regions of deficient

rain-fall, or of low relative humidity, and the territory draining into them are called *inland basins*, because they contribute no streams to any ocean. By far the largest area of the land lies on the Atlantic side of the main water-shed. Fully one half of the land on the globe contributes its drainage to the Atlantic, and only about one eighth to the Pacific and Indian ocean basins, respectively. The inland basins collectively cover about one fourth of the land surface.

The Discharge of Streams.—No stream discharges at its mouth all of the rain-fall which occurs in its basin. In traversing the basin, the streams are diminished in volume (1) by evaporation, (2) by subterranean channels leading into some other basin or to submarine outlets, and (3) by chemical change of the water into some other substance, either in the soil, in plants, or in animals. The diminution by evaporation is vastly greater than that from all other causes. The proportion of rain-fall discharged varies greatly in different basins, depending on the intricate local conditions which occasion the disappearance of water, such as relative humidity of the air, permeability of the surface rocks, character of the region with respect to vegetation, etc. No great basin discharges into the sea much more than one half the rain-fall it receives. The Yukon, the Magdalena, and the Rhine discharge about one half; the Amazon and the Mississippi about one fifth; and the Nile, whose lower course traverses a rainless region, but $\frac{1}{87}$th of the rain-fall of their respective basins. The average discharge into the sea from all streams in the world is estimated to be only one fourth to one fifth of the rain-fall on the land. This small proportion, however, amounts to about 6,500 cubic miles annually—a volume of water great enough to cover the whole United States, including Alaska, to a uniform depth of 9½ feet.


OCEANIC AND INLAND DRAINAGE BASINS.
PACIFIC OCEAN
ATLANTIC OCEAN
INDIAN OCEAN
NORTH POLE
EQUATOR
Drawn on the same projection as the map of Regions of Elevations & Depressions.
MAIN WATERSHEDS
AREAS OF LAND IN THE MAIN DRAINAGE BASINS.
Relative Areas
Atlantic
Arctic
Absolute Areas.
Of the Atlantic Ocean (inc. Arctic) 26.400.000 Sq. Miles.
" " Inland basins 11.500.000 " "
" " Pacific Ocean 7.500.000 " "
" " Indian Ocean 6.700.000 " "

Relative Size of Streams.—The true measure of the absolute size of a stream or stream system is the volume of running water it contains. This volume changes from day to day and from season to season, and depends upon so many factors, that its determination is practically impossible. The *relative* or comparative size of great stream systems is approximately indicated by the mean annual volumes of rain-fall occurring in their respective basins, which depends simply upon the mean depth of the rain-fall and the area of the basin. The opposite table indicates graphically the relative sizes of the thirty-three great river systems determined by this method.

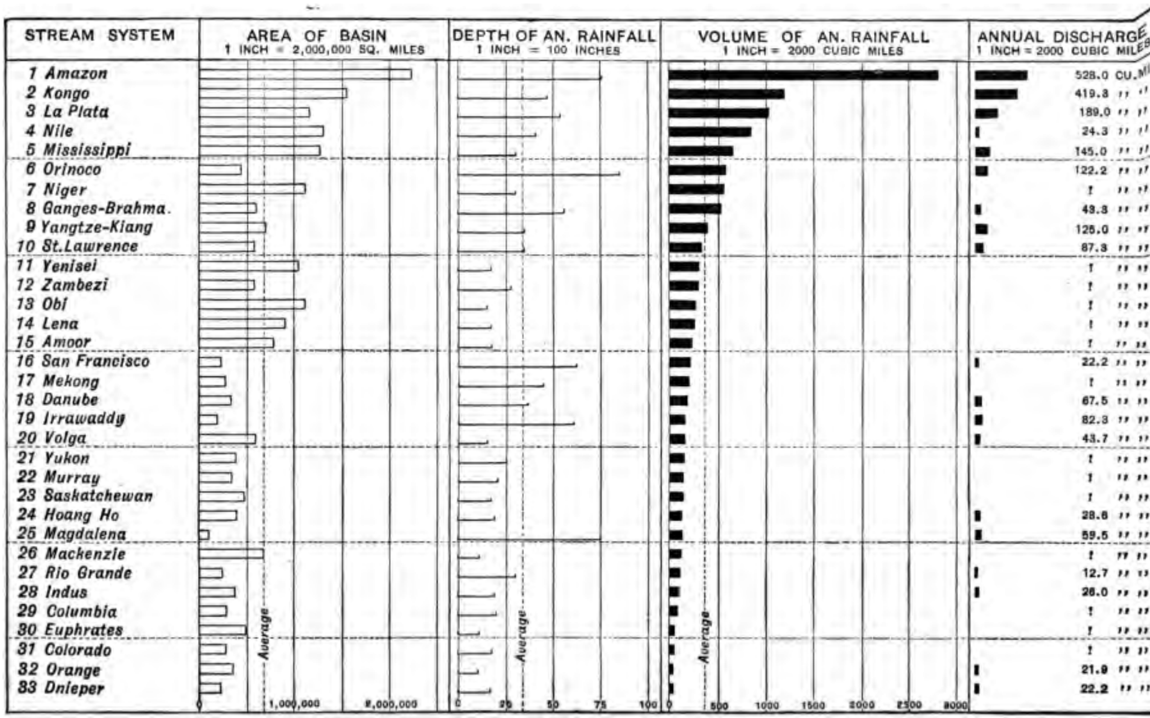
It will be noticed that some systems, as the Amazon, Kongo, La Plata, and Nile, owe their prominence both to the heavy rain-fall and to the great area of their basins. In others, as the Mississippi and the Siberian rivers, less than the average rain-fall is compensated by the great extent of their basins; while in still others, as the Orinoco, San Francisco, Irrawaddy, and especially the Magdalena, small basins are compensated by exceptionally heavy rain-fall. The discharge at the mouth of a system, and the length of its longest stream, are sometimes used as indications of its relative size, but a large system may lose most of its water in its lower course and discharge a relatively small quantity of water, while a long stream may be shallower and have fewer and shorter tributaries than a shorter stream; thus, the Nile, though three times as long as the Ohio-Alleghany, discharges only two thirds as much water, while the Mississippi-Missouri, the longest stream in the world, discharges but little more than one fourth as much water as the Amazon.

The Longest Rivers in the World.

Mississippi-Mo.,	4,192 miles.	Yenisei . .	2,950 miles.
Nile	4,018 "	Amoor . .	2,919 "
Yangtze-Kiang	3,156 "	Kongo. . .	2,881 "
Amazon . . .	3,061 "	Mackenzie, .	2,866 "

The Largest Mean Annual Discharges.

Amazon .	528 cubic miles.	Mississippi, .	145 cubic miles.
Kongo .	419 " "	Yangtze-Kiang	125 " "
La Plata .	189 " "	Orinoco . .	122 " "



STREAM SYSTEM
AREA OF BASIN
1 INCH = 2,000,000 SQ. MILES
DEPTH OF AN. RAINFALL
1 INCH = 100 INCHES
VOLUME OF AN. RAINFALL
1 INCH = 2000 CUBIC MILES
ANNUAL DISCHARGE
1 INCH = 2000 CUBIC MILES
1 Amazon
2 Kongo
3 La Plata
4 Nile
5 Mississippi
6 Orinoco
7 Niger
8 Ganges-Brahma.
9 Yangtze-Kiang
10 St.Lawrence
11 Yenisei
12 Zambezi
13 Obi
14 Lena
15 Amoor
16 San Francisco
17 Mekong
18 Danube
19 Irrawaddy
20 Volga
21 Yukon
22 Murray
23 Saskatchewan
24 Hoang Ho
25 Magdalena
26 Mackenzie
27 Rio Grande
28 Indus
29 Columbia
30 Euphrates
31 Colorado
32 Orange
33 Dnieper
Average
Average
Average
0
1,000,000
2,000,000
0
25
50
75
100
0
500
1000
1500
2000
2500
3000
528.0 CU. MI.
419.3 " "
189.0 " "
24.3 " "
145.0 " "
122.2 " "
? " "
43.3 " "
125.0 " "
87.3 " "
? " "
? " "
? " "
? " "
? " "
22.2 " "
? " "
67.5 " "
82.3 " "
43.7 " "
? " "
? " "
? " "
28.6 " "
59.5 " "
? " "
12.7 " "
26.0 " "
? " "
? " "
? " "
21.9 " "
22.2 " "

(Slopes exaggerated 500 times)

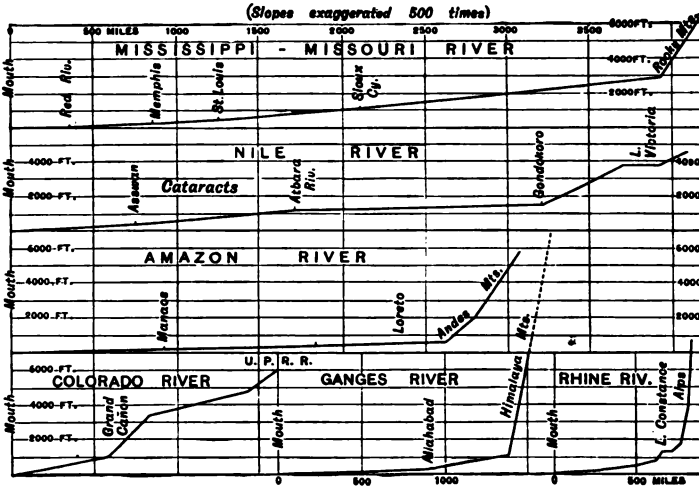


Fig. 88.

Slope.—No stream has a regular or uniform slope from its source to its mouth. If any stream be examined at low water, it will be found to present a succession of short but relatively steep descents, alternating with longer reaches where the fall is much less. Now, the speed or velocity of a stream depends mainly upon the inclination of its surface. The water creeps slowly over the long, flat reaches, but makes the shorter and steeper descents with a rush, forming *rapids* or *ripples* where the descent is an incline, but *cataracts* or *cascades* if the descent is vertical. If these minor irregularities of slope be disregarded, and only the general inclination be observed—as in the profiles, (Fig. 88)—the slope, though it varies in different parts of the course, will as a general rule be found, like that of mountain sides, to decrease in steepness as it is descended. The average fall per mile in the *lower course* of five of the rivers indicated above is from 2 to 6 inches, while *near their sources* it varies from 4⅔ to 120 feet to the mile.

Speed of Streams.—The velocity of streams is generally a little greater just below the surface, than at the surface or nearer the bottom; and is greatest near the middle of the stream. A stream may be considered as composed of a number of layers of water roughly parallel with the cross section of its bed (Fig. 89). The advance of each layer is somewhat retarded by friction. The bottom layer *a* is pressed upon by the greatest weight of water, and moving upon the irregular bed

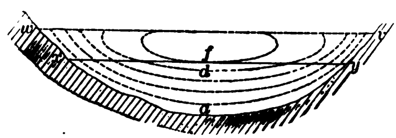


Fig. 89.

rock, its retardation by friction is greatest and it moves slowest. The friction of each successive layer above *a* is less than that of the layer upon which it moves, since it is pressed upon by a less weight of water. Hence, if the line *xy* represents the surface of the stream, the layer *d* occupying the central portion of the surface is retarded least by friction, and therefore flows fastest. If, however, the surface is raised to *wv* during a freshet, the layer *f*, being farther from the bottom, flows still faster.

The average speed of an ordinary river current varies from less than 1½ miles an hour at low water, to less than 6 miles at high water, while *exceptionally* rapid torrents probably never exceed a speed of 20 miles an hour. The Ohio River at Cincinnati, where its fall is 4 inches to the mile, has a mean surface speed of 1⅛ miles an hour when the water is low (6 feet deep). When the water is high (54 feet deep) the average current is nearly 6 miles an hour; that is, it is 6.35 miles in the channel and 5.85 miles per hour half-way toward either bank. The Mississippi River at Baton Rouge, where the fall is 3 inches per mile, has a mean speed at low water of 1½ miles, and at high water of 4 miles an hour.

Variations in Volume.—Owing to the intermittent supply of rain and snow water, many streams are subject

to great variations in volume. Rains, or the melting of snow, over a *considerable portion* of any drainage basin result in a greater or less rise of its streams. A short, heavy rain-fall, or the rapid melting of snow, though yielding a comparatively small volume of water, may, on account of its *suddenness*, cause a greater rise at a given locality than a greater but more gradual increase of volume. An exceptionally great or rapid increase in the volume of water in any basin may cause the streams to overflow their usual banks or channels, and spread over the adjacent lowlands, producing a *flood*, called a *freshet* in small streams.

The same volume of water causes streams to rise to different heights at different points along their course, depending upon the variations in the widths of the valley and the slopes of the stream. Where the valley is narrow, the same volume of water causes the stream to rise higher than where the water can spread out over a greater width of valley. High water tends to make the *surface* slope of streams uniform by increasing the slope on level reaches and decreasing it at rapids. Thus, the greatest known flood in the Ohio (1884) caused a rise of 46 feet above the "Falls" (rapids) at Louisville, but of 72 feet three miles below, at the foot of the rapids.

These fluctuations of volume, since they depend entirely upon the weather in the respective drainage basins, are always irregular in amount, and more or less irregular in time of occurrence. Local showers, falling on comparatively small areas, may be occasioned by many purely local and temporary conditions of the atmosphere, and therefore occur at irregular intervals; hence, *small streams*, whose basins lie more or less completely within the small areas of these local rains, fluctuate irregularly.

The volume of water which flows at once over the surface from these showers, though ample to swell the smaller streams, is seldom sufficient to have a very perceptible effect upon the main streams of a great river

system, whose basin embraces a very extensive area. Enough water to cause a marked rise in such streams is only supplied by wide-spread or long-continued rains or by the melting of extensive snow-fields. Such effects are caused chiefly by the varying amount of heat received from the sun at different seasons, and therefore depend largely upon the regular movement of the earth in its orbit. Hence, a certain corresponding regularity is noticed in the recurrence of fluctuations of all *large streams*.

The Ganges and the Nile exhibit special regularity in time of recurrence of low and high water, but a greater or less degree of regularity is exhibited in this respect by all large streams. The increasing heat of summer not only melts the snows on the lofty Himalayas, but causes the moist monsoon winds to blow *from* the ocean; the resulting rains aid the snow-water in swelling the Ganges. An annual rise begins in May and continues till September. The rise is from 30 to 45 feet at Allahabad, and 7 to 10 feet at Calcutta. In the same manner the moist spring monsoons deposit excessive rainfall on the highland of eastern Africa from Abyssinia to the equator. Thus, the headwaters of the Nile begin to rise annually about the 1st of May, but it takes two months for the rise to reach Cairo, where, by about October 1st, the river has reached a height of between 18 and 30 feet above its June level. Throughout the United States the rains are more uniformly distributed over the year, but the great Rocky Mountain tributaries to the Mississippi are generally highest through June and July on account of the snow-water from their elevated sources. The snow about the less elevated sources of the Ohio, however, melts earlier in the season, and February is the month of flood in that river. In consequence of the different times of flood in its large tributaries, the minor fluctuations of the lower Mississippi are somewhat irregular, but it is always above its mean level from January 1st to August 1st, and below it during the rest of the year. The usual range between low and high water in the Missouri increases from about 6 feet at Fort Benton, Mont., to about 35 feet at its mouth; in the Arkansas from 10 feet at Fort Gibson, Oklahoma, to 45 feet at its mouth. The usual range of the Mississippi above Hannibal, Mo., is 14 to 20 feet, increasing to 50 feet from Cairo, Ill., to Red River, and decreasing thence to nothing at its mouth. The range of the Ohio is about 50 feet.

CHAPTER XVI.

WORK OF STREAMS.

The waters wear the stones; thou washest away the things which grow out of the dust of the earth.—JOB XIV: 19.

Transportation.—It has been said (page 181) that a process, called *erosion*, is constantly at work over the surface of the land, this process consisting of the disintegration and removal of the land surface particle by particle. The weather is the principal cause of the general disintegration of the surface; *streams are the principal means of the removal* of the disintegrated material. During its transport, each particle becomes a tool with which the stream powerfully and rapidly disintegrates and wears away its bed, even if the bed consists of the hardest rock. This method of disintegration, which takes place only in the beds of running streams, is called *corrasion* to distinguish it from the more general disintegration of the whole surface of the land by the weather. Streams transport rocky material in three ways: (1) in solution, (2) in suspension, and (3) by rolling or pushing it forward along the stream bed.

In solution.—While rocky material is *in solution* or *dissolved* in water, it is, strictly speaking, no longer rock, its *molecules* having been separated to form a constituent part of the water. When in this form the rocky material accompanies the water in all its movements and to any distance, until some change of temperature or pressure renders the water unable to hold it all, when a portion of

the dissolved matter is *precipitated* into its true rocky form again.

In suspension.—The transportation of rock particles *in suspension* is entirely different, and is simply mechanical, depending upon the swiftness of the current and the size of the particles. Larger or smaller rock or soil particles are constantly finding their way into streams by their own weight or by the force of the winds, but chiefly through the wash of successive rains. Once in the stream their more rapid journey begins. The rock particles, being heavier than water, have a tendency to sink, and would go straight to the bottom if the water were still; but in its general advance over the irregularities of its bed, an intricate system of minor currents is set up in the body of the stream, which move upward and sideways, and occasion the "boiling" places, waves, and whirlpools always seen on the surface of rapid streams. These minor currents prevent the sinking of the finer rock particles, which are therefore carried along by the main current *in suspension.* Should the main current increase in velocity, the force of the minor currents increases, and larger particles can be held in suspension; should the speed of the main current become slower, the minor currents decrease in force, and the larger particles in suspension sink to the bottom. It is the material in suspension that causes the muddiness or turbidity of stream water; and the general increase in its turbidity after rains is occasioned both by the large amount of fine soil particles washed in by the rain, and by the ability of the stream to carry along more and larger particles in suspension when its volume and velocity are increased by the shower.

The capacity of running water for material in suspension increases very rapidly as its speed increases; **to double its** speed would increase its capacity about 64

times. Hence, very much more material is transported by streams in times of flood, or high water, than when the water is low.

If the material is fine enough to be held in suspension, the transporting capacity of water flowing at any speed is very great. If this capacity were reached, the stream would appear as a mass of very fine mud or "quicksand," just liquid enough to flow, and the water would form but one fourth of its weight; that is, out of every five cubic feet of the liquid mass, three cubic feet would be solid particles. It is very seldom that enough soil particles, small enough to be held in suspension, are washed into a stream at one time to fill it nearly to the limit of its transporting capacity; but such mud- or sand-streams are occasionally encountered.

Material pushed forward on the stream bed.—Innumerable particles and rock fragments, too large to be held in suspension, are yet small enough to be rolled forward along the bottom of streams with great force by the main current. It is to the attrition of such fragments and of those in suspension, that the wearing away or deepening of stream beds is chiefly due. The size of these fragments, the force with which they advance, and hence the amount of deepening of the stream bed, or *corrasion*, increase very rapidly with the speed of the main current. The deepening of any stream bed by corrasion of course increases the steepness of slope of its valley sides; hence, the speed and corrasive power of all its tributary streams are increased, and this increases the slope, speed, and corrasion of all streams flowing into these tributaries. Therefore, the deepening of any stream bed increases the amount of disintegration and transportation—that is, of *erosion*—over its entire basin.

Sedimentation.—Wherever the speed of a current is checked from any cause, the water is no longer able to hold the larger particles in suspension; they therefore settle to the bottom to be either rolled along or left be-

hind as sediment, according to the force yet remaining in the main current. Should this current be further checked, the water becomes clearer as still smaller particles in suspension are deposited upon the bottom, until, upon the cessation of all currents, the water would become perfectly clear as the smallest particles in suspension are gradually deposited.

The amount of material transported varies greatly in different streams according to their slopes and the character of their basins, and in any one stream it varies greatly with the stage of water. Many calculations on different rivers indicate that streams on the average transport about $\frac{8}{10000}$ths* of their weight of mineral matter. That is to say, the rivers of the world, in the aggregate, transport *each year* from the land to the sea enough rocky material to make a sharp crested range of mountains 1,000 feet high, a mile wide at the base, and 30 miles long.

The quantity of material in *suspension alone* discharged annually by the Mississippi would make a range of hills 500 feet high, half a mile wide at base, and over a mile long. The Ganges discharges annually about the same amount of matter in suspension, while the suspended matter which the little Rhone discharges annually into the Mediterranean would make a pyramid a mile square at the base and 230 feet high.

Formation of Valleys.—By thus removing the particles disintegrated by atmospheric agencies, and by the attrition of these particles upon the stream bed, the streams themselves, during the long ages of the past, have hollowed out and formed the valleys in which they flow, and the same processes are to-day modifying the

* In suspension,	.000558—T. M. Reade, Am. Jour. Science, 1885, page 298.
In solution,	.000186—J. Murray, Sc. Geog. Mag., 1887, page 76.
Rolled along bottom,	.000067—Hump. and Abbott, Hyd. Miss. Riv., page 148.
Total,	.000811

shape of every foot of the land. The variety in the slopes and shapes of valleys results from the varying rate of corrasion and weathering in different regions as determined by slope, climate, and hardness of the rocky material composing the earth's surface.

The Curve of Erosion.—In spite of these causes of variation, the general slopes of different parts of the land, and of different valley bottoms in particular, have a rough resemblance in becoming *flatter as they are descended.* (See diagrams, pages 165 and 212.) This arrangement of slopes results from the invariable action of running water and the peculiar curve which it produces in the general slope may therefore be called the curve of corrasion or *erosion.*

The surface of the land is a succession of steep and gentle slopes. All parts of it are, constantly or intermittently, subjected to the action of running water;—the beds of permanent streams, constantly; and other parts of the land, during and immediately after rains. The stream or rain-water flowing swiftly down the steep slopes corrades more material than its slower current is able to transport over the flatter slope below; hence, a deposit is formed against the bottom of the steep descents as at *a*, *a*, (Fig. 90). Subsequent action of the same kind causes, for similar reasons, further deposits at *b* and *c*. Thus, the profile of the slope gradually acquires the form of a succession of curves of erosion. But the deposits are formed of material corraded from the higher parts of the slope *d*, *d*, which are thus flattened as indicated by the dotted lines. When this part of the slope becomes as flat as the surface of the deposit at *b*, the checking of the current and the settling of sediment ceases, while corrasion begins to cut away the deposit at that point. Prolonged action of this kind gradually wears away all irregularities, and reduces the slope to a single curve of erosion (Fig. 91). The constant action and greater volume of water on stream beds has frequently reduced

Fig. 90.

their general profile to a single curve from mouth to source; but in many streams the reduction has not yet advanced so far, and two or more curves can be distinguished in the general profile of the stream, as in the Colorado and the Nile (Fig. 88). The general surface of the land, acted upon by smaller volumes of water, and only at intervals, is reduced more slowly, and

Fig. 91.

its profile, except in its more general features, presents a long succession of curves of erosion. The deposit of corraded material at the place where a current of water is checked by encountering a gentle slope occasions the familiar *alluvial cones*, or fan-shaped heaps, which invariably occur where swift mountain streams or the common wet weather gullies of steep hillsides encounter the more gently sloping plain.

Fig. 92.—Alluvial Cones in Utah.

The steepness of the sides of valleys depends upon the relative rapidity of the corrasion of the stream bed at the valley bottom, and the more general weathering of its sides by rain, frost, etc. Where corrasion is the more rapid, the valley is deepened faster than it is widened; and its sides are steep, giving it more or less the shape of a V. When weathering is the more rapid, the valley is widened faster than it is deepened, its sides become flatter and lower, and its cross section is more basin-shaped. The general rapidity of weathering is usually about the same in the same material in all parts of small basins, but the corrasive power of the stream decreases rapidly as it advances down the successively gentler slopes of its bed. Hence, as a general rule,

valleys are narrow and relatively deep in the upper course of streams, but gradually become wider and relatively shallower as the stream is descended, and in the lower course of large streams may become so wide and flat as to lose entirely all visible side slope and become practically plains. Thus, the lower Mississippi valley, from Cairo to the Gulf, is a gently sloping plain varying in width from 20 to 70 miles.

The rapidity of weathering on the valley sides is not always the same, however, throughout the same drainage basin; it varies considerably with the amount of rain-fall. If part of the course of a stream traverses a region of either very heavy or very light rain-fall, the effect is impressed on the shape of its valley. Heavy rain-fall increases the rate of weathering of the valley sides and of the adjacent upland, and a proportionately wider and shallower valley is the result. Light rain-fall has the opposite effect, and favors the formation of deep, narrow valleys, with steep side-slopes. Thus, the lower valley of the Nile has a very gentle slope, and corrasion is correspondingly slow; but it lies in so dry a region that the rate of weathering is still slower, and a comparatively deep, narrow valley is produced. When the rain-fall is very slight and the slope of the streams is very great, a *cañon*, or valley of exceptional narrowness in proportion to its depth, is formed. Noted examples of this are afforded by the Colorado, Virgin, and many other streams of the Rocky Mountain plateau region.

The character of the material has an important influence upon the general transverse shape of valleys. Thus, the streams which traverse the Great Plains, though they have a steep slope and traverse a region of scant rain-fall, produce valleys so wide and shallow as scarcely to merit the name *valley*. This is because the rock of the region

Fig. 93.—Grand Cañon of the Colorado, at Toroweap.

weathers so rapidly that its surface is always covered with a great depth of sand and soil particles which slide into the streams from the sides as fast as other particles are removed from the stream bed by the current. Thus, the stream becomes overloaded with sediment, and maintains a deposit of sand upon its bed which it can not remove. The bed is thereby protected from corrasion; hence, the

valleys are constantly getting wider without getting deeper.

The rivers which flow from the Rocky Mountains across the Great Plains, like the Arkansas and the Platte, have unusually steep slopes, being about as steep as the Colorado. But, after leaving the mountains, they cut no cañons or deep valleys, while the Colorado has cut profound ones. The difference in the two cases is due to the fact that the river troughs of the Great Plains are deeply buried in sand, the waters of the rivers being loaded to their utmost capacity, while the Colorado is able to transport more sediment than it receives. The rocks in its trough are to a great extent bare owing to the scouring action of the material in suspension, and the channel is continuously deepened.

Variety in the Character of Material.—When hard strata alternate with soft ones, the sides of a valley form a series of steep and flat slopes, the steep slopes occurring in the hard strata. The rapid erosion of some soft strata frequently undermines the edges of a hard overlying stratum. A line of overhanging cliffs along the valley side is thus formed (Fig. 94). Fragments of the cliff often fall from their own unsupported weight, aided by the prying action of freezing water in the joints (page 13). If such fragments collect faster than erosion can remove them, they gradually form a *talus*, which may cover and for a time protect the softer strata from further erosion.

Fig. 94.

Cataracts and Cascades.—If the main or a tributary stream in a valley whose sides contain lines of cliff be ascended until the stream bed reaches the foot of the cliff, a water-fall is encountered. It may be a *cataract*, called a *cascade* in small streams, or simply *rapids*, according to circumstances. If the strata are nearly horizontal, and the stream *clear* and large enough to reduce and carry

away the rock fragments about as fast as they fall, the overhanging form of the cliff is constantly maintained. The stream leaps over this as a cataract, leaving a space under the hard stratum and behind the falling water which is constantly filled with spray, and into which people can frequently enter from the sides. The occasional but continued detachment and fall of fragments from the overhanging cliff, causes a constant recession of the cataract *up stream.*

The cataract of Niagara, midway between lakes Erie and Ontario, is about 165 feet high. Though by no means the highest, it is probably the grandest cataract in the world on account of its great volume of water. Immediately above the fall the Niagara River is almost a mile wide. It flows over the brink with an average depth of about four feet, and a greatest depth of perhaps twenty feet. Enough water flows over every twenty-four hours to make a lake a mile square and 821 feet deep. Below the fall the river occupies a narrow valley, or cañon, which gradually increases from 200 to 300 feet deep. The cañon is so narrow that in it the river has only one eighth to one fourth of its former width. The stratum of hard stone that forms the brink of the cataract outcrops along the top of the cañon, forming a line of cliffs, beneath which a talus of fragments slopes steeply down to the water's edge. Seven miles below the falls these cliffs turn sharply away from the stream to right and left, and the river flows thence through a low, open country to Lake Ontario. The place where the cliffs turn away from the stream undoubtedly marks the original position of the cataract, while the seven miles of cañon is the amount the fall has receded up stream from the constant undermining and breaking away of the hard stratum. Judging from the present rate of recession of the fall, about three feet a year, it has required 12,320 years for the excavation of the cañon. It has probably not required quite so long a time, however, for at present a large portion of the river—the American Fall—falls into the *side* of the cañon and is consequently engaged in increasing its width and not its length. The cañon is so narrow because the talus of hard rock fragments from the cliffs on its side slopes forms a protecting layer over the soft strata beneath, and thus prevents to a great extent the undermining and downfall of the cliffs.

Rapids, or a series of very low falls, are generally formed instead of a single cataract where the strata have a very steep dip, or when the stream is muddy, or is not sufficiently powerful to prevent the formation of a talus under the edge of the horizontal strata; for in these cases the form of an overhanging cliff can not be maintained, and the water simply rushes down a steep broken incline. Rapids are also formed by many other obstacles to the uniform descent of streams.

Since, within certain limits, the corrading power of a stream increases with the amount of sediment it carries, muddy streams may wear away the hard stratum forming the brink of a water-fall faster than the weather erodes the soft strata beneath, and thus prevent the formation of an overhanging cliff and a cataract, the water simply descending a steep incline as a rapid. Indeed, cataracts are almost invariably confined to streams carrying clear water, such as those issuing from lakes. Most of the conditions favoring the formation of great cataracts exist along the steep course of the Colorado River, and the fact that no cataracts occur is believed to be due to the great corrading power which the large amount of sediment carried gives to its current. It is believed that the noble cataract of Niagara would be quickly reduced to a simple rapid were the water of the river very muddy instead of being very clear as it is.

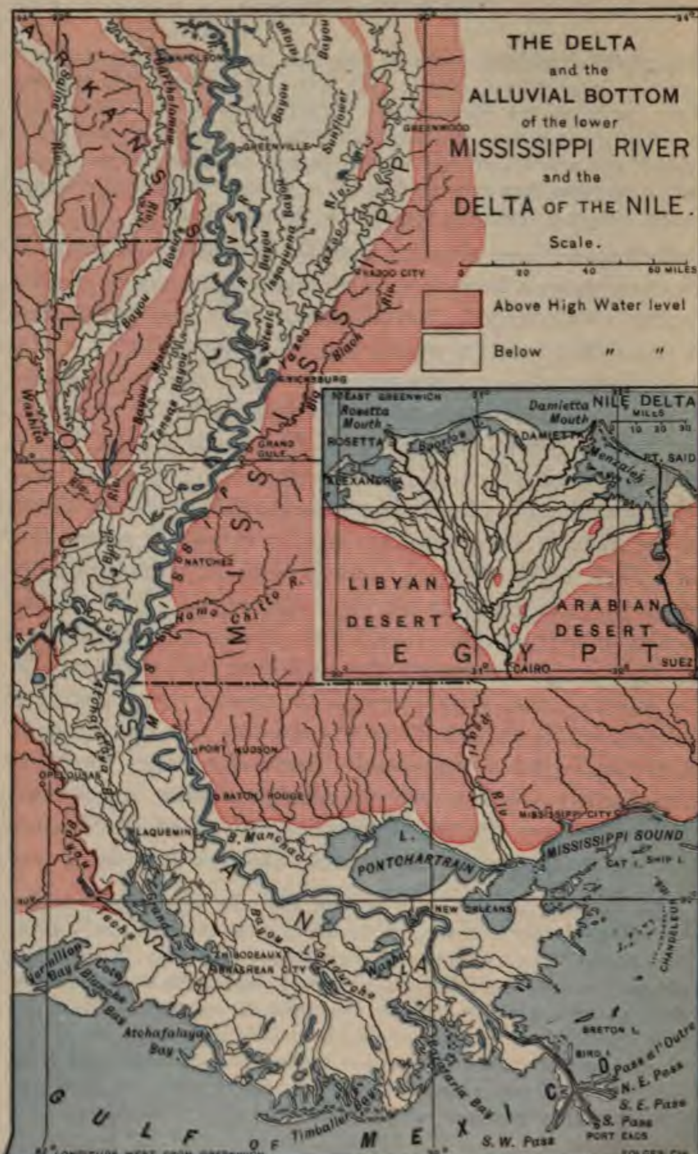
Immense Age of Watercourses is often suggested by [illegible] of this [illegible],—such [illegible] as [illegible] the [illegible] mountains [illegible], being common. [illegible] the [illegible] of valleys which are every-where [illegible] almost [illegible] the [illegible] of flowing water, proves that in very many instances the courses of the larger streams are older than the neighboring hills and mountains.

Instances of [illegible] in many regions, but are specially conspicuous in [illegible] the Appalachian region of New York, Pennsylvania, and Virginia, the numerous parallel mountain ridges seem to have influenced but little the course of the larger streams, which flow directly across the ridges one after another in a succession of deep, narrow gorges or water-gaps.

such as the Highland gorge of the Hudson, the Delaware Water Gap, the Susquehanna Water Gap above Harrisburg, the Harpers Ferry gorge on the Potomac, etc. This indicates that the general course of these streams was established before the present mountains existed, and was maintained by the constant corrasion of the stream bed. Corrasion thus cuts the notches or gaps in the several ridges as erosion slowly hollows out the valleys between them.

Deltas.—Upon entering a body of water with little or no current, as a lake, a stream deposits its sediment, producing a submerged alluvial cone, which may slowly rise to the surface of the water, and be converted into a fan-shaped area of low, marshy land. The stream generally traverses this new-made land in several radiating channels, and by the continued deposit at the several mouths causes the land constantly to advance further into the lake. The extensive deposit of this kind, accumulating at the mouth of the Nile is exceptionally regular in shape, resembling the Greek letter *delta* (Δ), and from it the name delta has come to be applied to all such formations. All streams flowing into the ocean would form deltas but for currents strong enough to remove the sediment, or subsidence of the earth's crust rapid enough to absorb it, as fast as it is deposited at the mouth of the stream. Deltas are common only in lakes and nearly land-locked seas, for these being nearly tideless, are less likely to have strong currents; such are the Mediterranean, the Gulf of Mexico, the Arctic Ocean, the North Sea, the east Asia seas, etc.

The dividing of the main stream into the radiating branches which gives the peculiar form to the delta is the result of the varying action of the stream at low and high stages of water. Throughout its lower course, where the slope is very slight, the stream at low water occupies a contracted channel, and the current is just about able to move along the load of sediment. At high water, the stream spreads out over the whole valley bottom, the low water channel marking the deepest water and swiftest current, while on each side of the channel the current is much slower, and a great deal of sedi-


THE DELTA
and the
ALLUVIAL BOTTOM
of the lower
MISSISSIPPI RIVER
and the
DELTA OF THE NILE.
Scale.
0 20 40 60 MILES
Above High Water level
Below " "
NILE DELTA
ARKANSAS
MISSISSIPPI
LOUISIANA
GULF OF MEXICO
LIBYAN DESERT
ARABIAN DESERT
EGYPT
GREENVILLE
VICKSBURG
NATCHEZ
BATON ROUGE
NEW ORLEANS
PONTCHARTRAIN
MISSISSIPPI SOUND
ROSETTA
ALEXANDRIA
CAIRO
SUEZ
PT. SAID
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PORT EADS
LONGITUDE WEST FROM GREENWICH
FOLGER CH.

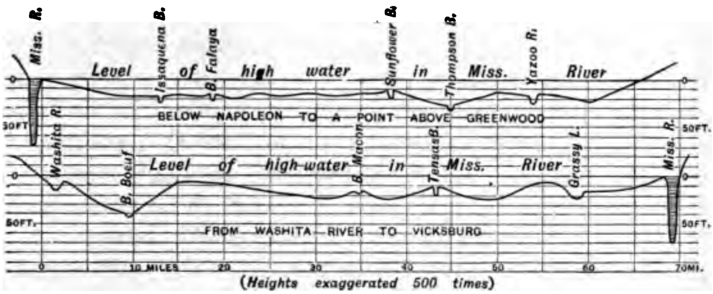


Fig. 95.—Profiles across the valley bottom of the Mississippi River.

ment is deposited and left as a layer of mud when the water subsides. Now, this deposit is greatest on the banks of the low water channel, where the rapid current suddenly changes to a slow one; these banks are thus raised higher than the valley bottom farther away from the low water channel. The banks continue to be raised in this manner by successive floods until they become so high that the weight of the stream when "bank full" bursts the bank at some weak point, thus causing a "crevasse," through which part of the water in the main stream drains off into the lower land and follows down the side of the valley bottom. When this occurs at a considerable distance from the mouth, the side stream, after a longer or shorter course, as a *bayou*, generally finds its way back into the main low water channel again; but when crevasses occur near the mouth of the stream, the bayous form independent mouths, and by the corrasion of the soft layers of sediment forming their beds, may eventually increase in width and depth until they rival or exceed the former main stream in volume. The Atchafalaya Bayou of the Mississippi is the highest one having an independent mouth, and its divergence, at the mouth of Red River, is therefore called the head of the Mississippi delta.

Estuaries.—When a coast region is sinking with relative rapidity the streams are apt to empty into deep and narrow bays, *fiords* or *estuaries*, formed by the submergence of the lower part of the stream valley. Chesapeake and Delaware bays and the indentations of the Maine coast are such submerged valleys.

Course.—As a rule, the path of a stream becomes more devious as the stream is descended, because the declivity and corrasive power usually decrease in that direction. A mass of relatively hard material in the bed, operates to deflect the stream toward the side composed of softer material. A small but *steep* tributary generally tends to deflect the main stream toward the opposite side of its valley, for the tributary, being *swift*, brings down particles which the more gentle current of the main stream can not carry. A delta-like deposit or bar, therefore, advances into the main stream and forces its current against the opposite bank, which is rapidly corraded into a loop-like bend. A large tributary, during its floods, may in this way deposit material entirely across the main stream, whose waters are thus dammed back into a long, deep pool, while they flow over the deposit as a shallow rapid. Whenever a stream is deflected from a straight course, the current tends to increase the bend.

Thus, in any bend of a stream, as *BD* (Fig. 96), the inertia of the current causes it to follow the course of the dotted line; hence, the banks at *B*, *C*, and *D* are corraded fastest, while sedimentation frequently takes place at *F*, *E*, and *G*, and sand-bars, beaches, or mud flats advance into the river as the opposite bank recedes. Hence, the *channel* containing the deepest and swiftest water is always found close to the *concave* bank of a stream. The effect of this is most marked in the lower course of streams where the banks are composed of soft sediment. Figures *X*, *Y*, and *Z* indicate progressive states of a bend in such places. In *Y* the narrow neck of the loop has been cut across. The descent through this short "cut-off," being steeper than it is around the loop, the cut-off rapidly increases in depth and width by corrasion until it becomes the main channel. The ends of the loop are soon filled with sediment, and the crescent shaped lake (Fig. *Z*) alone remains to mark the former site of the river.

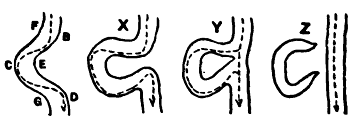


Fig. 96.

CHAPTER XVII.

GLACIERS AND LAKES.

Hast thou entered into the treasures of the snow?—Job xxxviii: 22.
Ye shall not see wind, neither shall ye see rain; yet that valley shall be filled with water, that ye may drink.—II Kings iii: 17.

Glaciers.—Wherever more snow falls in winter than is melted in summer, the snow tends to accumulate on the ground and to move down the slopes. Dry and powdery at first, the snow, in passing to lower levels, gradually becomes compacted, by the accumulating weight above and the freezing of percolating water from the melting of the surface snow, into a white, granular mass called névé. At greater depths this mass is compressed into more or less transparent ice. Great tongues of this ice creep, far below the snow line, down the valleys heading in the névé, and constitute *glaciers*.

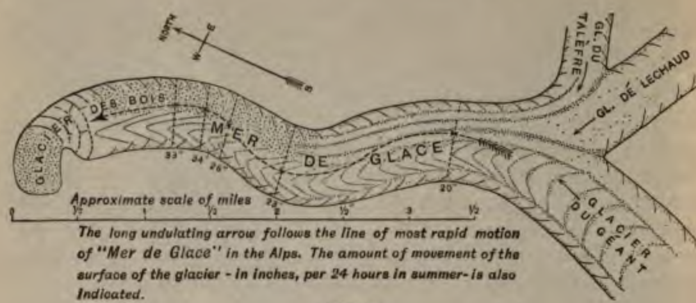
Occurrence.—Glaciers can only form in regions of perpetual snow, and in such regions large glaciers can form only where the snow-fall is copious. Hence, near the equator glaciers are formed only on mountains exceeding 16,000 feet in height, but they occur at successively lower elevations in higher latitudes, and in the frigid zones on hills of very moderate elevation. In any latitude glaciers are generally largest on those eminences of sufficient height which are *first* encountered by the vapor-bearing winds from the sea, and on the sides of these eminences which are turned *away* from the sun; that is, on the north

A view up the glacier "Mer de Glace"—Upper Savoy, France.

side in the northern hemisphere, and on the south side in the southern hemisphere.

The Himalaya Mountains, though near the tropic of Cancer, are so lofty and so well supplied with vapor by the south-west monsoon that they bear immense glaciers; one has a length of over 35 miles. The moderately high mountains of Alaska, and the low mountains of Norway, being near the Arctic Circle and well supplied with moisture, also bear large glaciers. The Alaskan glaciers are probably larger than any others in torrid or temperate zones. On all the high peaks of the Sierra Nevada and the Cascade Mountains from central California northward, glaciers are found; on mounts Lyell and Dana, Cal., they are less than a mile long; Mount Shasta, Cal., has one two miles long, while one on Mount Tacoma, Washington, is ten miles in length, and surpasses in size and grandeur many of the Swiss glaciers. The glaciers of the Alps have been visited more than any others. They are found principally about Mount Blanc, in France, Monte Rosa, Finsteraarhorn, and the Bernina Alps in Switzerland, and the Oetzthaler Alps in the Tyrol. Each group has glaciers more than six miles long and a mile or two wide, while Aletsch Glacier, on the slope of Finsteraarhorn, has a length of 14 miles. The thickness of these glaciers is estimated at between 500 and 1,000 feet. All these glaciers, however, sink into insignificance when compared with those of the polar regions. These form at comparatively low elevations, and, covering the *entire* country with a thick ice sheet, descend into the sea, where great masses break off and float away as icebergs. The Humboldt Glacier, of Greenland, is thought to be half a mile thick at its sea front.

Movement.—Glaciers creep downward at a rate varying with the slope, the season, and the rain-fall, but seldom, if ever, at a rate rapid enough to be perceptible without measurements. Careful observation has proved that the movement of a glacier resembles in many respects that of the current of a river. It is faster on steep than on flat parts of its bed; at the surface than toward the bottom; and near the center than at the sides of the surface. In the curves of its course, the glacier moves fastest not at the exact center, but at a point in its surface nearer the convex side of the curve.



The long undulating arrow follows the line of most rapid motion of "Mer de Glace" in the Alps. The amount of movement of the surface of the glacier - in inches, per 24 hours in summer - is also indicated.

Fig. 97.

Along the line on the surface of the Mer de Glace where movement is fastest, the mean speed is 27 inches a day in summer and about one half as much in winter, or about 600 feet a year. Hence, this glacier requires more than 25 years to traverse the three miles of its length. The thicker Greenland glaciers move more than 30 feet a day, and almost as fast in winter as in summer.

If a square block of ice be placed in a mold of any other shape and subjected to hydraulic pressure, the ice is crushed to powder, which takes the shape of the mold, and immediately re-freezes into a solid mass again. The phenomenon is called ***regelation.*** The amount of pressure required to crush the ice is comparatively slight, but increases as the temperature of the ice falls below its melting point. This experiment illustrates why the solid ice of a glacier, which is brittle rather than plastic, constantly moves downward and conforms to the bends and irregularities of its bed as if it were a truly plastic substance like wax, thick honey, or thick tar. The deepening snow of the névé presses its lower layers into solid ice, and at last crushes this ice and squeezes it outward down the glacial valleys. But simultaneously with their movement, regelation unites the particles of crushed ice into a solid mass again, which thus transmits pressure to the lower portions of the glacier. The faster movement of glaciers in summer is owing to the fact that at that season the ice is nearer its melting point, and hence yields more easily to pressure than in winter. In addition to these movements, the glacier *slides* bodily forward to a greater or less extent, and rapidly corrades its bed.

Ablation of the Surface.—The surface of the glacier is subject to constant lowering by evaporation, and the

entire ice mass, but especially the surface below the snow line, loses more by melting in summer than it receives by snow-fall in winter. The average lowering, or *ablation*, of the surface of the Mer de Glace is probably six inches a day during summer. If, owing to a succession of exceptionally mild winters or hot summers, the amount melted exceeds the amount brought down by movement, the lower end of the glacier retreats up the valley. If the conditions are reversed, the end of the glacier advances down the valley. The Swiss glaciers have been advancing since 1875.

Lateral moraines.—The sides of valleys through which glaciers descend, being usually steep and in regions of great elevation, are exposed to great variations of temperature and rapid erosion. Large quantities of sand, soil, and rock fragments thus find their way to the glacier, and are carried by it down the valley. This rubbish is specially abundant near the sides of the glacier, where it forms long mounds on either edge of the ice. These are called *lateral moraines*. When a second glacier joins the first from a tributary valley, the adjacent lateral moraines unite and are carried down the center of the united glacier as a *medial moraine*.

Each tributary glacier-bearing valley thus produces a medial moraine on the main glacier below its junction. The Mer de Glace has five medial moraines, one of its tributaries having one and another two when they join the main glacier. Medial moraines remain distinct and well marked for some distance, but are gradually distributed by the differential motion of the glacier over its entire surface. Large quantities of moraine matter protect the ice beneath from rapid melting; thus, medial moraines frequently cover the summit of a ridge of ice, while great blocks of stone on the glacier are, by the melting of the surrounding surface, left perched as "rock tables" on pedestals of ice sometimes 8 or 10 feet high.

Terminal moraines.—At the end of the glacier, the moraine rubbish is dumped upon the ground. If the

glacier is stationary or advancing, the rubbish accumulates to form a curved ridge called a *terminal moraine;* but if the glacier is *retreating*, the moraine matter is left as a coating of approximately uniform depth but very irregular surface, covering the ground exposed by the retreating glacier. Moraine matter left in this generally distributed manner is usually called *glacial drift* to distinguish it from the same material accumulated into terminal moraines.

Glacial Abrasion of Rocks.—The rocks carried down on the surface of glaciers undergo no friction and retain their angularity. But vast numbers tumble into the *crevasses*, which at some places open in the glacier to great depths, owing to irregularities in the slope of the bed or to the differential movement of the glacier. These rocks, with others torn from the bed or sides, work their way to the bottom, where, pressed down by the overlying ice, they are rasped over the rocky bed by the forward movement of the glacier; most powerful abrasion results, both of the rocks embedded in the ice and of the underlying bed rock. Long, continuous scratches, or *striæ*, are indented upon each by the harder particles in the other, while the exceedingly fine powder resulting from the abrasion acts like emery powder, and gives the rock over which the glacier moves a smooth and polished surface. As a result of this abrasion, the ordinary V-shape of valleys is often changed into a U-shape, the rock of their bottom and sides is planed and worn down, and all their sharp angles removed; and where the bed rock is soft, it may be hollowed out into deep basins, while, where relatively hard, it is worn into smooth, dome-shaped eminences striated in the direction of ice movement.

The melting and lowering of the glacier's surface sometimes leaves its lateral moraines stranded on the valley sides to mark a former height of its surface. The rock tables on the surface, or the

worn and rounded bowlders in the body of a glacier, are also sometimes left stranded on the steep valley sides among rocks of an entirely different kind. These are called "perched" or "erratic" rocks, and are sometimes left on such precarious foundations that the slightest push would apparently be sufficient to set them in motion down the slope. When glacial drift is removed from in front of a retreating glacier, the bed rock is always found to be smoothed, polished, and striated.

Glacial Streams.—A stream of water always issues from the lower end of glaciers. It is derived partly from springs, partly from surface waters higher up the glacial valley, but chiefly from the melting of the ice. The water is charged with an extremely fine light gray silt, formed by the constant abrasion of the rocks, which gives it a peculiar milky color, and it retains this peculiarity for a long time. This sediment forms a deposit of stiff, bluish clay, quite impermeable by water, and in marked contrast to the yellow mud deposited by rivers generally.

Former Extent of Glaciers.—Indications of glacial action on the valley sides high above the present surface of glaciers, and the occurrence of old terminal moraines, drift, polished rock surfaces, erratics, etc., not only far beyond the end of glaciers, but over vast regions hundreds and even thousands of miles from any existing glacier, prove that at a comparatively recent period in the past, glaciers had a much greater extent than at present. The whole northern half of North America and Europe are thus glaciated. The mountain summits are striated and polished, and the lowlands are deeply buried under accumulations of drift. This region in each continent must have been covered, as Greenland is to-day, by an immense sheet of ice, so thick that only the highest mountain peaks protruded above its surface. Many circumstances indicate that the movement of these continental glaciers, in Europe, was outward in all directions from the high-


GLACIERS & GLACIATED REGIONS
Glaciated regions
Glaciers
NORTH AMERICA
SOUTH AMERICA
NEW ZEALAND
EUROPE
ASIA
AFRICA
AUSTRALIA
TROPIC OF CANCER
EQUATOR
TROPIC OF CAPRICORN
ANTARCTIC CIRCLE
(Unexplored)
(Unexplored)

lands of Norway, while in the United States the movement was from the Canadian Height of Land.

The southern limit of this vast glacier can not be determined exactly. A terminal moraine (Fig. 98), from one to several miles broad, has been traced west from Cape Cod through the intervening states into the Dakotas and the Dominion of Canada, and forms a limit which the ice *certainly* reached. But glacial drift extends many miles south of this moraine in some localities.

Fig. 98.

Effects on the Relief of the Land.—The thickness of this glacial drift has been ascertained in many localities in the United States, and has been found to vary from a few feet to four or five hundred feet. It is generally

thickest in the vicinity of the moraine, and is generally thicker in the valleys than on the higher land. Almost all the valleys in the drift regions are more or less filled with drift gravel, sand, and the peculiar blue clay of glacial origin. The drift very generally fills not only the bottom of valleys, and forms the bed of the stream, but frequently forms a series of terraces along either side of the valley to a height of several hundred feet above the stream, which indicate the amount of drift removed by the stream since the glacial period (Fig. 99).

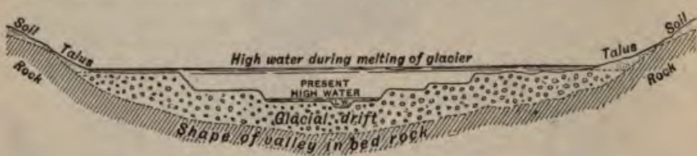


Fig. 99.

Cincinnati is built upon two such drift terraces of the Ohio valley, at elevations of 65 and 130 feet above low water in the river. The bed of the Mississippi River at La Crosse and Prairie du Chien is more than 100 feet above bed rock, and of the Rock River at Janesville, Wis., more than 250 feet.

The drift deposit, especially where greatest, in the region from the moraine northward, entirely blocked up and buried many old valleys, destroying the ancient drainage lines, and, by its own irregularities, presented a new and peculiar surface, formed in disregard of drainage demands. In these irregularities water collected, giving rise to innumerable lakes (Fig. 98), which are the special feature of the region north of the moraine in both America and Europe.

Formation of the Great Lakes.—While thousands of small lakes in and north of the moraine region occupy simple depressions in the surface of the drift, the larger lakes, including the American Great Lakes, probably occupy old preglacial valleys of atmospheric erosion, which, however, were modified by movements of the earth's crust and greatly broadened and deepened by the abra-

sion of the glaciers themselves, the bulk of the drift south of these lakes being the material so removed.

There are indications which render it not unlikely that the preglacial valleys of lakes Michigan and Superior were tributary to the Mississippi; the Michigan valley possibly south-westward through Illinois, where an ancient valley, completely obliterated by a depth of 200 feet of drift, has been traced; and the Superior valley, either westward in the vicinity of St. Croix River, where the drift is very thick, or southward by some deep, narrow, and as yet undiscovered valley, across the upper peninsula of Michigan into the Michigan valley. The Huron-Erie-Ontario valley probably found an outlet through the St. Lawrence. There are strong indications of the existence of a deeply buried and concealed valley connecting these lakes. The filling of these natural channels at places divided the valley into separate basins, and forced the waters in each basin to seek a new channel at the lowest point of its water-shed.

Lakes.—Whenever the water of a stream system, in its downward course over the land, meets an obstruction to its further advance, its current is checked, and it tends to accumulate on the upper side of the obstruction to form a *pond or lake*. The constant addition of water from the stream tends to raise the level surface of the lake to the lowest point at which the water can escape through or over the obstruction to form an outlet. As the surface of the land is generally *sloping* and seldom precipitous, a very slight rise of the lake usually occasions a great increase both of its width and length, and hence of the water surface exposed to evaporation. It thus sometimes happens that before the lake rises to a point at which it can find an outlet, the increased evaporation from its surface equals the amount of water constantly added by tributaries. In this case the water surface can rise no higher, and a lake lying in an inland basin—that is, a lake having no outlet—is formed. Thus, lakes may be divided into two classes: (1) those having outlets, and (2) those having no outlets. It is an almost invariable rule that lakes with

outlets contain *fresh* water, while lakes without outlets contain *salty or bitter* and undrinkable water.

Fresh Water Lakes.—Since the water of all streams contains more or less mineral matter in solution, and since, upon evaporating, water leaves all impurities behind, the greater relative evaporation from the wider lake surface tends to increase the proportion of dissolved impurities in the lake water; hence, lake water usually contains more matter in solution than the average water of its tributary streams. When the lake has an outlet, however, this difference is so slight that the taste of the lake water is not usually affected, and the difference does not increase beyond a certain point, for the impure lake water is constantly escaping by the outlet, while purer water is constantly entering the lake through its tributaries.

Salt Water Lakes.—In lakes having no outlets, the constant loss of *pure* water by evaporation, and the constant addition of the small proportion of mineral matter dissolved in the tributaries, causes a constant increase of the mineral matter in the lake water, until, eventually, it becomes *saturated* with some mineral, that is, can hold no more of *this mineral*, though other minerals present may continue accumulating. Further accessions of the saturating mineral are deposited in solid crystals on the lake bottom. Long before the water becomes saturated, the mineral is in sufficient quantity to have imparted to the water its peculiar taste, if it has any. The proportion of dissolved minerals in various waters is here given:

1 barrel of average fresh water contains about $\frac{13}{1000}$ of a qt. of minerals.
1 " " " ocean water " " 3 quarts " "
1 " " " Dead Sea water " " 22 " " "

The kinds of mineral in any salt lake, and the relative amount of each, depend partly, of course, upon the character of the rocks composing its tributary basin, and

partly upon the effect which different minerals in solution have upon each other. Some minerals limit the ability of water to hold in solution certain other minerals, while they entirely prevent the water from holding in solution still other minerals. The principal minerals in solution, and their proportion (by weight) are given below.

Bodies of Salt Water.	Total in Solution. *Lbs. per 1,000*	Common Salt.	Chlorides and Sulphates Magnesia and Lime.	All Other.
Kara Booghaz (gulf of Caspian)	285	29%	67%	4%
Dead Sea (average)	243	26	70	4
Great Salt Lake	150	79	10	11
Mediterranean Sea (average) .	38	78	15	7
Open Ocean	35	78	19	3
Black Sea	18	79	16	5
Open Caspian Sea	13	63	29	8
Average proportions,		62%	32%	6%

Bodies of Fresh Water.	Total in Solution. *Lbs. per 1,000*	Common Salt.	Carbonates Lime and Magnesia.	All Other.
Average River Water	$\frac{162}{1000}$	3%	64%	33%
Lake Michigan	$\frac{145}{1000}$	4	78	18
Average proportions,		3½%	71%	25½%

It might be expected that the *proportion* of the different minerals in salt lake water would be the same as in its fresh water tributaries, but simply increased in *quantity*. The above table indicates, however, that 94% of the mineral in the salt waters consists of common salt, and the *chlorides* and *sulphates* of magnesia and lime, while in the fresh waters these minerals form less than 30%, since 71% is composed of the *carbonates* of lime and magnesia. Not only are aquatic plants and animals constantly robbing water of its dissolved carbonate of lime, but when the very slight quantities of chlorides and sulphates usually found in fresh waters have accumulated to a certain extent in the lake or sea, they cause the water to

deposit almost all of its *carbonates*, thus leaving the salty and bitter chlorides and sulphates in excess in the solution. When certain chlorides and sulphates accumulate still more, they act in a similar manner upon each other, and thus cause a deposit of much of the common salt (chloride of sodium). Thus, owing to the large proportion of chloride of magnesia in the water of Kara Booghaz and the Dead Sea, it can not hold nearly as much salt as that of Great Salt Lake, in which less chloride of magnesia has as yet accumulated. This is indicated graphically in Fig. 100. This diagram also indicates that the Dead Sea, Great Salt Lake, and parts of the Caspian—all of them simply lakes without outlets—contain a vastly

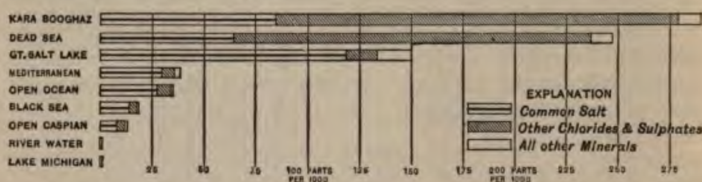


Fig. 100.—Amount and Proportion of Dissolved Minerals in Various Waters.

greater proportion of mineral matter in solution than the water of the ocean or of its arms—the Mediterranean and Black seas. As the surface of both the Caspian and Dead seas is considerably below sea-level, it is thought they may at one time have been arms of the ocean, which have been separated from the ocean by the upheaval of the intervening region. But even if this is the case, by far the greater part of their intense "saltness" is due to the same causes that would gradually convert any fresh water lake into a salt lake if its outlet were permanently closed.

The checking of the current of tributaries upon entering a lake causes a deposit of more or less of the solid particles held in suspension. Hence, all lakes are being gradually obliterated, not only by the corrasion of the outlet channel, which tends to lower the lake surface, but by the deposit of sediment, which tends to fill up the lake basin. On account of this deposit, the water of every lake and of its outlet is clearer than that of its inlet streams. Relatively large lakes usually contain very clear

water, since they have the slowest current and the least amount of matter in suspension. When, in addition to the large relative volume of the lake, the water of the tributaries is clear, as is usually the case in regions of hard rock, the water of the lake is exceptionally limpid and transparent.

Lakes fed by streams flowing from glaciers—as Geneva, Maggiore, Como, and many others—have usually a beautiful blue color, but really their water is less clear than that of lakes of large relative volume fed by ordinary streams. Much of the silt of glacial streams is so fine that the slight current of the lake can hold it in suspension. These fine particles in suspension, by reflecting only the blue rays of light, give the water its peculiar color, just as the fine particles of the air give the sky its azure tint (see page 104).

Effect on Floods.—Floods in tributary streams, upon entering a lake, are spread out over its relatively great area, and thus do not materially raise its level surface. Hence, neither lakes, nor streams issuing from them, are subject to such great variations of level between low and high water as are streams tributary to lakes, or those in whose course no lakes occur.

Thus, there are no such great floods in the Great Lakes or their outlet, the St. Lawrence, as occur annually in the Ohio, Missouri, and other rivers whose courses contain few or no large lakes. The mean annual fluctuation between high and low water in the Great Lakes is less than 1¼ feet. In the Ohio, at Cincinnati, it is more than 50 feet.

Temperature of Lakes.—The temperature of the surface water in lakes varies with the seasons, but on account of the great specific heat of water it does not vary so rapidly, and hence not to so great an extent, as that of the overlying air or the neighboring land surface. During the summer the water is generally cooler than the air, which it therefore tends to cool, while during the winter the water tends to keep the adjacent air warm. If the winter

temperature at the surface of fresh water lakes falls to or below that of the maximum density of water (p. 25), the temperature at the bottom is 39°, and, if the lakes are deep, it remains constant throughout the year. From this bottom water in such lakes, the temperature increases to that of the surface in summer, but may decrease to a surface temperature of 32° in winter.

Distribution.—Lakes are much more numerous in some regions than in others. As a general rule, lakes are more numerous near water-sheds than elsewhere. Near water-sheds, streams are short and small; hence they carry but little sediment, and possess little power either to corrade lake-forming obstructions or to fill up and obliterate lake basins. There are five kinds of regions where lakes are particularly abundant, the lakes being generally fresh if the rain-fall is abundant, but salt if the rain-fall of the region is scanty.

(1) **Glaciated regions**, or those whose surface has been covered with irregularities by the abrasion or drift-deposit of former glaciers. North-eastern America and north-western Europe are such regions, the old terminal moraine forming in the United States a sharp boundary between a vast lake region on the north and a comparatively lakeless region on the south (Fig 98).

(2) **Mountainous or hilly regions generally.**—In these regions the valleys are steep and narrow. The one quality favors the erosion of large masses from the sides of the valley; the other permits a comparatively small quantity of material to make a high obstruction across the valley; consequently, mountain lakes are generally very narrow and very deep. If the five Great Lakes in the comparatively flat portion of the United States be compared with the five Alpine lakes, Geneva, Constance, Como, Maggiore, and Garda, it will be found that the Great Lakes have an average width of one fourth, but the Alpine lakes of only one ninth of their lengths. The average of the greatest depths in the Great Lakes is 705 feet, and of the Alpine lakes 1,491 feet.

(3) **Non-glaciated, basin-shaped plateau regions having a copious rain-fall.** The most remarkable of these extends south-

ward from Abyssinia in eastern Africa. It contains a number of lakes which rival our Great Lakes in size.

(4) **Regions of scanty rain-fall in general.**—These lakes are seldom large; they generally have no outlet, and hence contain salt water, and many of them are entirely evaporated during the drier seasons of the year. Almost all the salt lakes of the world occur in regions having a mean annual rain-fall of less than 10 inches (see chart, page 76). Lakes are rather numerous in these regions for the same reason that they are numerous near water-sheds—the supply of drainage-water being small and often intermittent, the streams make little progress in cutting away lake-forming obstructions or filling up lake basins. Among the largest salt lakes are Caspian, Aral, and Dead seas and Balkash Lake of Asia, and Great Salt Lake of Utah. Though they lie in nearly rainless regions, they all receive tributaries from regions of more copious rain-fall. The Caspian Sea is five times as large as Lake Superior, and though it receives the Volga and five smaller rivers, the evaporation from its vast area is so great that its surface lies 85 feet below the level of the ocean, and 171 feet below the lowest point in its water-shed. The main body of the sea is only brackish, for the great shallow and nearly land-locked gulfs on its eastern coast—as the Kara Booghaz, which is nearly half as large as Lake Erie—lose so much water by evaporation that a constant current flows into them and acts as an outlet to the main sea. The water of these gulfs is much salter than ocean water on the same principle that the water of the Mediterranean is slightly so. (See page 144.)

(5) **Low and sandy sea-coasts** are frequently fringed with shallow, brackish lakes or lagoons. They occur along the whole east coast of the United States south of Cape Cod. They are separated from the ocean by a narrow beach of sand, and receive the drainage of the coast region through small streams. The narrow beach is the joint result of the sediment of the small streams and the sand piled up by the sea waves and the wind.

CHAPTER XVIII.

MOUNTAIN STRUCTURE AND LAND SCULPTURE.

Every valley shall be exalted, and every mountain and hill shall be made low: and the crooked shall be made straight, and the rough places plain: and the glory of the Lord shall be revealed.—ISAIAH XL: 4.

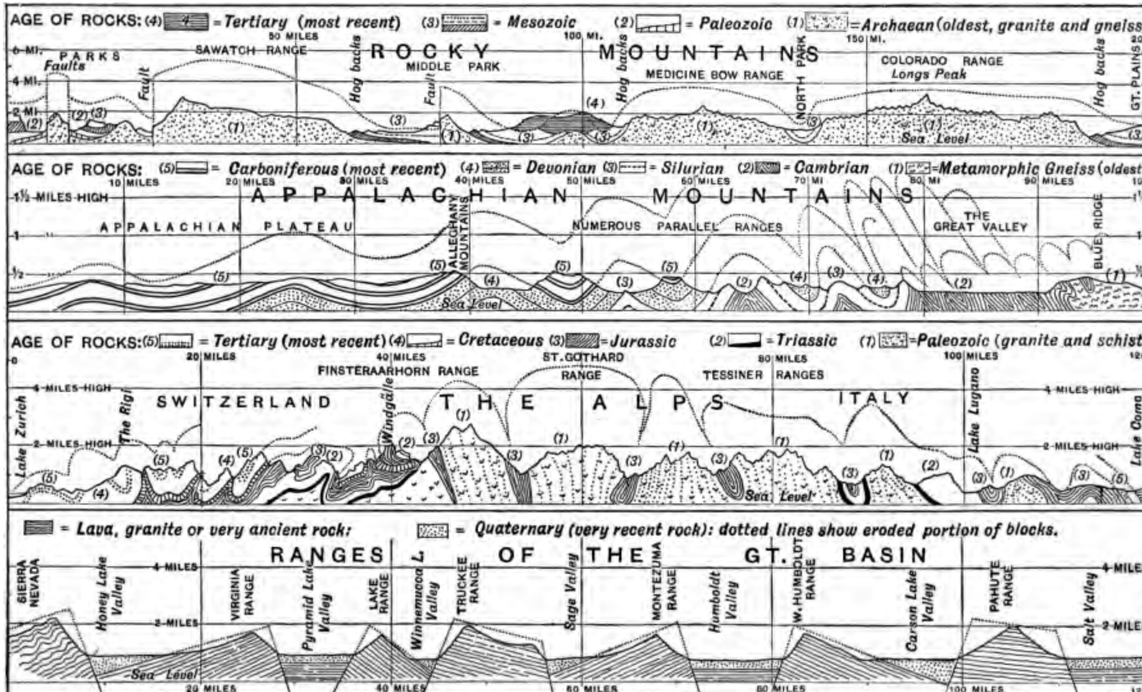
Mountain Formation and Sculpture.—The repeated uplifts and subsidences of the earth's crust which have resulted in the gradual formation of the continental plateau, have in general thrown the rock strata which compose the land, into a series of wave-like undulations. In some extensive regions the undulations are so broad and low that the curvature is quite imperceptible, the strata lying apparently horizontal or having a very gentle and uniform slope over great areas. This, in general, is the position of the strata composing plains and plateaus. In the long and comparatively narrow mountain regions, however, which traverse each of the grand divisions, the undulations are much narrower and higher. In some regions the strata have been thrown into a succession of huge open waves, while in others the waves have been crowded together into a series of closely compressed folds, so that the strata stand directly on end or are even overturned, older rocks lying on top of newer ones. Long faults or fractures where the strata have slid up or down or sideways hundreds and even thousands of feet, are very numerous in mountain regions. The rocks are generally more or less completely metamorphosed, hard gneiss and massive granite often occupying large areas, while dikes

and hardened outflows of lava are almost invariably found in some parts of the region.

The atmospheric agents, and streams of running water, which are constantly disintegrating, removing, and hence lowering all parts of the land surface, are especially energetic and rapid in their action in these regions of high elevation, and steep and broken strata. A covering of rock, probably many thousand feet thick, has been thus removed from all parts of every mountain region. It is believed that a thickness of *five miles* has been so removed from much of the Appalachian chain, and that at least one mile has been eroded from the entire region between the Rocky and Wasatch mountains.

This enormous erosion has seldom been uniform, however, over a mountain region. Other things being equal, it has been greatest where the elevations were highest, the slopes steepest, and the rocks softest. The elevated tops and steep sides of the folds of the strata have thus generally been most deeply eroded, and hence older rocks are generally exposed along the crests than along the troughs of the folds. On account of this great but unequal erosion, the crests of the mountains do not always conform to the crests of the folds; but, in general, mountain ranges are simply the projecting remnants of those portions of folds, which, on account of the greater hardness or the more stable position of the strata, have been best able to resist erosion. The great folds and faults in the earth's crust have therefore determined the direction and general position of mountain ranges, but the shape of a range—every peak, ridge, spur, valley, and cañon—is directly and *entirely due to erosion.*

Mountains of simply folded strata.—The simplest mountain chain is that which is carved from a single broad fold of very thick strata; such is the Uinta range



Natural Sections across several Mountain Regions.

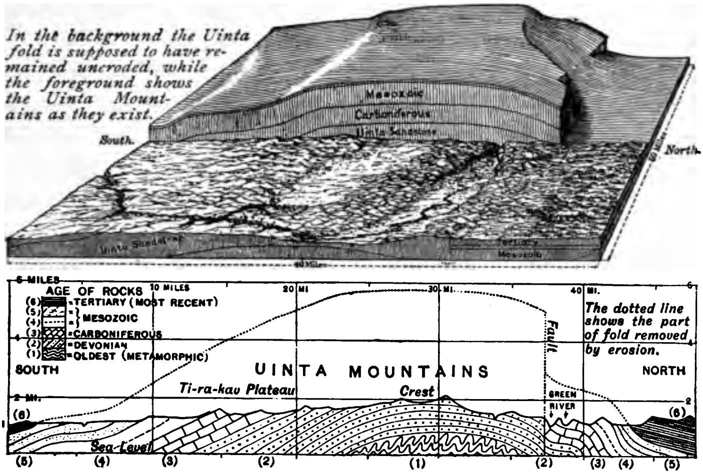


Fig. 101.

of Utah (Fig. 101). Although a thickness of 3½ miles of rock has been eroded from this range, the deeply buried rocks now exposed along its crest have been but little changed by metamorphism. The three main ranges of the Rocky Mountains in Colorado have been carved from a series of three broad, flat, Uinta-like folds; but in this instance the underlying metamorphic granite has been exposed by the erosion, and forms the mountain crests, while the upturned remnants of the unchanged stratified rocks which once covered the higher parts of the range form a series of "hog backs" or foot-hill ridges along its base (see Rocky Mountain section opposite).

Mountains of closely folded strata. — More frequently mountain chains have been carved from an upheaval consisting of a greater number of more pronounced folds. When the structureless granite has not been exposed by erosion, the projecting edges of the harder

strata composing the folds form a well defined and regular series of long, parallel ridges of nearly uniform height, such as constitute the Appalachian chain of the United States (see page 250), and the Jura Mountains of France and Switzerland. In many of the larger chains of the world, however, the great thickness of stratified rock removed from the top of the folds has exposed either the granite or equally hard gneiss, *i. e.*, granite in which some of the lines of stratification are still obscurely visible. The section across the Alps (page 250) may therefore be regarded as typical of all great mountain chains.

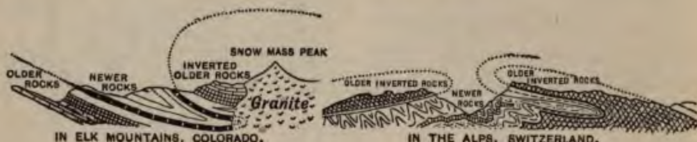


Fig. 102.

The greater folds of most mountain regions are corrugated by many minor plications. The portions of these minor foldings left by erosion often render the structure of certain regions exceedingly complicated, as indicated in Fig. 102. In other localities the structure is entirely concealed by great outflows of lava thousands of feet thick and hundreds of square miles in extent; such is notably the case in the Cascade Range in the states of Oregon and Washington.

Mountains Produced by Faultings of the Strata.—The numerous and nearly parallel ranges of the Great Basin, western Arizona, and northern Mexico are somewhat different in structure. The region between the Sierra Nevada and the Wasatch Mountains, and extending from Idaho to Mexico, is composed of very gently folded rocks deeply buried in places by extensive outflows of lava. A series of nearly parallel fractures, hundreds of miles long and fifteen to thirty miles apart, traverses this entire

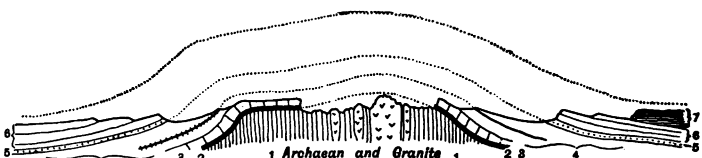
region and divides it into long, narrow blocks. Many facts prove that the whole region was once more elevated than at present, but has subsided thousands of feet, and during the subsidence the blocks have been tilted sideways. The uptilted side of these blocks, carved by subsequent erosion, forms the isolated mountain ranges of the region (see section of Basin Ranges, page 250).

The rate of mountain upheaval, either by folding or faulting, is always an exceedingly slow process, the rocks giving way a few inches, or at most a few feet at a time, and at very long intervals, as the stresses accumulate. It is certain that such movements are taking place at present in many mountain regions, notably throughout the great and nearly continuous highland on the convex side of the continental plateau. Hence, notwithstanding the enormous thickness of strata eroded from their tops, many mountains may never have been higher than they are at present, erosion having planed down the surface about as fast as it was upheaved. Many of the older mountains, however, as the Appalachians and the mountains of northern Europe, in which the upheaval has probably long since ceased, have probably been greatly lowered by the subsequent erosion.

The extreme slowness of upheaval is conclusively proved in many cases by river gorges, cañons, or water gaps, cut directly across the mountain range (page 226). This is plainly seen in the Uinta Mountains. The great Uinta fold rose directly across the upper course of the Colorado River, but it rose no faster than the river deepened its channel; hence, the river has not been deflected from its course, but flows through the mountain in a deep cañon, which the river cut as the fold rose.

Age of Mountains.—Most mountain chains have been upraised by a *succession* of these gradual uplifts, separated by long ages of rest or subsidence. The time of the upheaval which left the region permanently above the sea

determines the "age" of the mountain. The Appalachian chain was permanently raised above the sea before the close of the paleozoic era; the Sierra Nevada at the close of the Jurassic period; the Rocky Mountains at the close of the cretaceous; and the Coast Ranges as recently as the close of the miocene. Hence, the Appalachians have been subjected to much longer erosion than the mountains of the west. The difference in the length of time that various ranges have been exposed to erosion may partly account for the fact that the oldest mountain chains are never very high, while the highest ranges are invariably among the youngest. The high and nearly



Age of rocks. 1 = Archaean, 2 = Silurian, 3 = Carboniferous, 4 = Triassic, 5 = Jurassic, 6 = Cretaceous, 7 = Miocene (most recent).

Dotted lines indicate shape of eroded portion of fold. Vert. scale 6 times horizontal.

Fig. 103.

continuous ranges on the convex margin of the continental plateau, and the Alps and the mountains of Venezuela are all of recent upheaval, while most of the detached and lower ranges near the concave or Atlantic margin are much older.

The age of mountains is determined by the ages of the unconformable strata involved in the folds. A section across the Black Hills of S. Dakota illustrates the process (Fig. 103). There are two lines of unconformity in this range: between the ancient archæan (1) and the overlying Silurian (2) rocks, and between the comparatively recent cretaceous (6) and the overlying miocene (7). This indicates the history of the range, which is typical of mountain ranges in general. During archæan time the rocks of the nucleus were deposited beneath the sea as horizontal strata, were then folded and metamor-

phosed, and the strata separated by great protrusions of granite. They were elevated above the sea, and the tops of the folds removed by erosion. At the close of archæan time began a long continued subsidence below the sea again, during which the successively more recent rocks of the Silurian, carboniferous, triassic, Jurassic, and cretaceous periods were deposited in horizontal strata above each other on the upturned edges of the archæan strata. Then another period of upheaval ensued, which gradually bent all the horizontal strata up into the great flat arch shown by the dotted lines, and raised them permanently above the sea. This upheaval took place soon *after* cretaceous time, for the unconformable strata (7) contain *fresh* water fossils of middle tertiary age, and are composed of material eroded from the higher parts of the arch, and must have been deposited in an old fresh water lake about its base. Hence, these mountains are of eocene age, since the uplift from which erosion is still carving them took place during the first period of the tertiary era.

Thickness of Sediments.—The ragged and upturned edges of strata in all mountain regions prove that before upheaval and erosion the thickness of stratified rock in these regions was exceptionally great. In the plicated Appalachian region the stratified rocks were eight miles thick, while in Indiana, where the *same strata* are nearly horizontal, they are known to be less than one mile thick. Now, the region where sediment is to-day accumulating fastest is a comparatively narrow belt of sea bottom along the margin of the continental plateau. The incessant erosion of material from the land, and its constant deposit in this "littoral" belt, disturbs the subterranean equality of pressures (page 151), and causes some regions of the land to rise, while the narrow marginal region of sea bottom subsides as weight gradually accumulates upon it. Thus, during the lapse of ages, sediment many miles thick may be deposited in these regions, the water remaining comparatively shallow all the while.

No theory of mountain upheaval yet advanced is complete and satisfactory. The long and narrow shape of

mountain regions, their rough parallelism with coast lines, and the comparative proximity of all the younger and higher mountains to the sea, together with the fact that sedimentary rocks are exceptionally thick in these regions, are all to be easily explained by supposing that mountain chains mark the general position of former marginal belts of sea bottom, which, after a longer or shorter period of subsidence, underwent great but gradual upheaval to form an elevated border to the previously existing land. It is generally believed that the great mountain systems have been formed by the successive uplifts of such marginal regions, and there are indications that the upheaval and accompanying plication, folding and faulting of the strata are primarily due to the gradual increase of subterranean temperature, and the consequent resistless expansion of the deeply buried rocks in such localities. But satisfactory reasons have not yet been found to account for the vast and relatively local variations of temperature in these thick accumulations of sediment, required to convert them from regions of subsidence into regions of exceptionally great elevation.

It is not impossible that the accessions to the width of the continental plateau, caused by the upheaval of the marginal belt of sea bottom, have taken place alternately on its two sides. The most recent accessions have been on the convex or Pacific side, which in general seems to be still rising, and in consequence of its elevation the streams and sediment of most of the land have been directed into the marginal region of the concave or Atlantic side, where, therefore, the foundations of the great mountain chains of the future are possibly now being laid. Indeed, the site of such a chain is possibly already marked out by the Lesser Antilles or Windward Islands.

Land Sculpture.—While erosion has been greatest in mountain regions, the whole surface of the land has probably been lowered many hundreds, or even thousands, of

feet by the rains, frosts, and winds of countless centuries; and the position and relative hardness of the different rock strata, by influencing their resistance to erosion, have determined the alternation of hill and valley in the lowland regions of comparatively horizontal rock strata.

In nearly horizontal strata, the corrasion of the main valleys leaves the intervening region as broad, flat-topped plateaus. The multiplication and deepening of tributary valleys eventually cuts up the plateau into irregular series of hills, with rounded outlines and nearly uniform height. The western part of the Appalachian table-land from New York to Alabama is thus cut up, while the eastern part

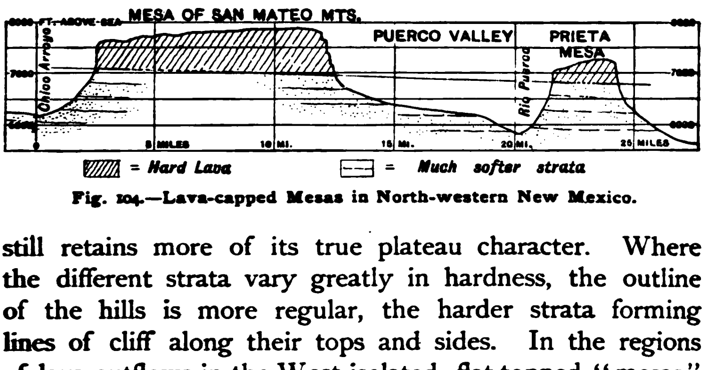


Fig. 104.—Lava-capped Mesas in North-western New Mexico.

still retains more of its true plateau character. Where the different strata vary greatly in hardness, the outline of the hills is more regular, the harder strata forming lines of cliff along their tops and sides. In the regions of lava outflows in the West isolated, flat-topped "mesas" or "table mountains" are numerous, the hard lava resisting the erosion which lowers the surrounding regions (Fig. 104). Where the horizontal strata are very soft, as in the numerous extensive regions of "bad lands" of the West, erosion has carved the surface into great numbers of steep, isolated cones and pinnacles, whose soft sides are scored by the rain streamlets into countless straight grooves. These upright flutings, together with the lines of horizontal bedding, suggest regularly laid masonry, and

Fig. 105.—Forms of Erosion in Washakie Bad Lands, Wyoming.

give the isolated masses, when seen at a little distance, the aspect of a gigantic city in ruins (Fig. 105).

Gently Inclined Strata.—A common effect of erosion on gently inclined strata is shown in the diagram (Fig. 106). A succession of long, parallel lines of cliff are

Fig. 106.

formed, separated by plains often many miles in width, which drain toward the base of the cliffs above. The surfaces of the plains are the harder strata which form the crest of the terminating cliff. The gradual breaking away of fragments slowly carries the lines of cliff backward down the incline of the strata. The wash of rain torrents carves the face of the cliffs into a succession of deep bays

with bold promontories between. The widening of adjacent bays frequently detaches the ends of the promontories, which, by the recession of the main cliff, are thus left as isolated "buttes" far out upon the plain below. Gradual weathering eventually disintegrates the hard capping strata of the buttes, and the butte rapidly disappears. Such lines of cliff, sometimes 2,000 feet high and hun-

Fig. 107.—Vermillion Cliffs, Utah, showing Outlying Buttes.

dreds of miles long, are very common in the Colorado Plateau district (Fig. 107). When some of the cliff-forming strata are *conglomerate* (rock composed of great bowlders cemented together), its disintegration and recession frequently leave detached high, slender "needles" of soft strata, capped by a hard bowlder. These needles are frequently hundreds of feet high, and stand until the gradual weathering of the soft strata diminishes the support of the capping bowlders, which at last topple over and the rains rapidly reduce the needles. Other peculiarities in the relative hardness of the various rocks cause the outlyers of the receding cliffs to weather into great natural arches and other fantastic forms (Fig. 108).

In sharply folded strata, the tendency of erosion is always to wear away the top of the fold most rapidly, for

Fig. 108.—Various Fantastic Forms of Erosion.

not only is the rock in that locality most apt to be greatly fissured, cracked, and weakened by the strains in folding, but the position of the strata is an unstable one, for when erosion has excavated a valley in the trough of a fold (Fig. 109) the inclined strata on the sides thus deprived of their support tend to move downward as a land-slide, which partially or wholly fills the valley and delays the erosion of the trough, while erosion proceeds with undiminished

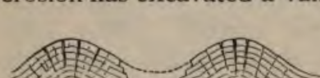


Fig. 109.

activity on the crests and sides of the folds. This more rapid lowering of the surface under the crests than under the troughs of the folds is very conspicuous in all mountain regions of sharply folded strata, and the process has gone so far in the older mountains, such as the Appalachian, that the present ranges usually occur either along the troughs, or are composed of specially hard strata on the inclined sides of the folds, while in younger mountains, such as the Juras, the tops of the folds have not yet been so greatly lowered; but before they have suffered erosion as long as the Appalachians, the present mountain sum-

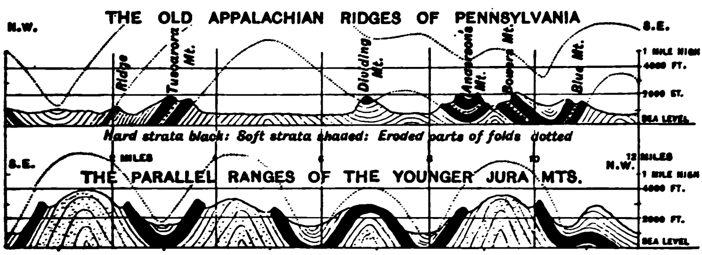


Fig. 110.

mits will probably be valleys, while the site of some of the present valleys may be occupied by ridges. In old mountains, therefore, such as the Appalachians and the mountains of northern Europe, most of the strata which occupied an unstable position have been removed, and consequently land-slides are of rare occurrence. In younger mountains, however, such as the Alps and the Sierra Nevada, many of the strata still remain in the unstable position, and extensive land-slides are numerous and often very disastrous.

Canoe-shaped Valleys.—Though many miles long, the individual folds of mountain regions are seldom nearly as long as the whole disturbed region in which they occur.

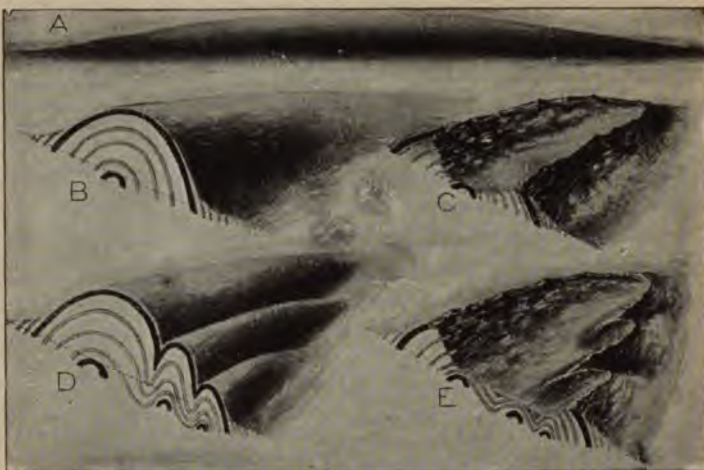


Fig. 111.—Formation of Canoe-shaped Valleys.

In reality, each fold is a greatly elongated *dome*. A sketch of such a dome-fold is shown in Fig. 111 (*A*), its internal structure being shown at *B*. The hard strata left projecting by the erosion of such a fold form mountain ridges which gradually approach and unite at either end of the dome-fold (*C*), thus inclosing one of the lozenge or canoe-shaped valleys so common in central Pennsylvania. Frequently several minor folds are pressed closely together, and this corrugated surface carried up into a great dome-fold (*D*). In this case, the erosion of the fold would leave the projecting hard strata in the form of a mountain ridge having curious zigzags in its trend (*E*).

Water Gaps.—The drainage of such confined valleys usually escapes through the inclosing mountain by a narrow notch or *water gap*. These water gaps have been cut entirely by erosion, but frequently at a point where the hard strata forming the mountain rim have been broken

and slightly displaced by a fault. Such a slight displacement has determined the position of the Delaware Water Gap.

The granitic crests of high mountains generally weather into a very jagged and irregular outline,—sharp, high peaks, alternating with relatively low passes. This peculiarity led to the name *sierra*—the Spanish word for *saw*. It is largely due to the absence in highly metamorphic rocks of the lines of stratification, which, by directing percolating water into definite channels, cause the stratified rocks to disintegrate with an approach to regularity.

CHAPTER XIX.

EARTHQUAKES.

Then the earth shook and trembled; the foundations also of the hills moved and were shaken.—PSALM XVIII: 7.

Earthquakes.—The constant wearing away of parts of the earth's surface by erosion, and the building up of the other parts by deposit, causes a very slow but incessant change in subterranean pressures and temperatures (page 186). These changes in pressure, and the tendency toward expansion or contraction accompanying these changes of temperature, place the deeply buried rocks every-where in various states of stress or strain. No region is exempt from such stresses. For years or centuries the stresses accumulate until they become greater than the rocks can bear. A sudden but slight movement of the strata then occurs, which relieves the stress, and for another long period the rocks remain practically stationary, while stresses again accumulate. Thousands of such slight movements, distributed over tens or hundreds of thousands of years, result in great upheavals or subsidences of the earth's surface, with faultings, flexures, or plications of the strata. The shocks or jars of each of these slight but sudden movements in deeply buried strata are rapidly transmitted through the rocks in all directions, and may reach the earth's surface, where they are felt over a larger or smaller area as an *earthquake*.

The subterranean movements which cause *great* earthquakes are generally sufficient in amount to cause perceptible displacement of

the surface strata. Such displacements are generally of a few inches or a few feet only, and usually consist of the elevation or depression of the strata on one side of a line of fault. Often the movement causing an earthquake occurs beneath the sea, and the overlying water conceals the surface displacement. Some severe earthquakes, and the great majority of minor ones, are caused, however, by subterranean fractures or movements so small that no sensible alteration in the surface topography results, the movement being entirely taken up by the redistribution of internal stresses.

Earthquakes are very common; it is probable that there is one every hour of the day in some part of the earth. They are more frequent in some regions than in others, but there is no region where they may not occasionally be felt. In mountain regions, and especially in the highest and youngest mountains, erosion is most rapid, and on the sea bottom, along the margins of continents, sedimentation is greatest; in these regions, therefore, subterranean pressure and temperature changes are most rapid, and earthquakes are frequent. Earthquakes are most frequent along the convex or Pacific side of the great continental plateau, which is bordered by the highest and youngest mountains. Earthquakes are least frequent in comparatively low and level inland regions, as the central part of South America, central United States and British America, Russia, Siberia, and central Australia, and in the sea bottom far from land. In these regions respectively, erosion and sedimentation are very slight, and occasion a relatively slow accumulation of subterranean stresses.

On an average, thirty or more earthquakes occur in the United States annually. More than 500 were recorded in this country during the sixteen years between 1872 and 1887, and doubtless many others occurred which were not recorded, especially in the sparsely settled region west of the Rocky Mountains. These earthquakes were distributed thus:

West of Rocky Mountains . .	240;	average,	1	every	24	days.
East of Appalachian Mountains,	210;	"	"	"	28	"
Mississippi Valley	80;	"	"	"	73	"

The regions shaken by the most perfectly recorded of these earthquakes are approximately indicated on the accompanying map. It gives a graphic idea of how common earthquakes are even in the Mississippi Valley, which is one of the most stable regions on the land surface of the globe. Many earthquakes west of the Rocky Mountains probably affected a more extensive region than some of those indicated, but are not shown upon the map because their record in that thinly settled region does not indicate even approximately their extent.

Elastic Waves.—Almost all rocks, and many other solids, are highly elastic within minute limits; that is, they yield very slightly under great stress or pressure, and regain their former shape or volume immediately when suddenly relieved from stress. It is this property which causes an ivory or a glass ball to rebound when dropped upon a hard surface. In consequence of the elasticity of rock, the sudden relief from stress afforded by the occasional movements of subterranean strata throws the adjacent rock molecules into a state of very slight vibration. While the distance through which the molecules vibrate is so slight as to be invisible, the energy of the vibration may be very great—nearly as great as that of the accumulated stress which caused the movement. The vibrating molecules communicate a similar but less energetic vibration to neighboring molecules, and these to molecules still more distant. In this way a thrill or tremor, called an *elastic wave*, is transmitted through the rock from the locality of the initial jar in all directions with wonderful rapidity but gradually decreasing energy. Upon arriving at the earth's surface, the energy of the invisible vibration of molecules in the elastic wave causes the visible movements of the surface soil or the sensible shocks which constitute an earthquake. Hence, there are three features to be considered in regard to an earthquake: (1) the origin of the jar; (2) the transmission


A few of the
REGIONS SHAKEN
by
EARTHQUAKES
SINCE 1872
Month & year of each earthquake
is indicated in its boundary line.
Owens Valley Earthquake III-72
Sonora Earthquake V-87
Charleston Earthquake VIII-86
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
MEXICO
BERMUDA IS.
Folger Eng. Co.

(267)

of its energy to the earth's surface, and (3) the effects of this energy upon the surface.

The transmission of energy through a solid by an elastic wave may be made manifest by placing some light object, as a toy marble, in contact with one end of a long, heavy iron bar, and striking the other end of the bar with a hammer. The blow may not cause the slightest movement of the heavy bar as a whole, yet the molecules with which the hammer comes in contact are thrown into invisible vibration. The vibration is transmitted from molecule to molecule through the bar, and may impart sufficient energy to the light marble to cause it to start visibly and perhaps violently forward. If, instead of a marble, a cake of moist clay be made to adhere to the end of the bar, the transmitted energy may be sufficient to detach the clay cake. These experiments illustrate perfectly the three features of an earthquake: the hammer blow represents the initial jar; the invisible molecular vibration propagated through the bar represents the invisible transmission of energy as an elastic wave through the heavy crust of the earth; and the visible movement of the marble or clay represents the effect of this wave upon comparatively light surface objects, such as the soil, buildings, or weakly attached masses of cliffs, etc.

The Origin of the Jar.—All knowledge respecting the deeply buried origin of a jar must be gathered from observations of the effects of the earthquake at the earth's surface; and many circumstances render it exceedingly difficult to draw proper inferences from these observations, which are themselves difficult to make with accuracy. It seems to be true, however, (1) that the origin is seldom more than 12 miles below the surface; it may occur, however, at any depth less than this; (2) that the size of the shaken region bears a certain relation to the depth of the origin, a small shaken region always indicating a relatively shallow origin; (3) that the energy of the jar is approximately indicated by the size of the shaken region, a large shaken region indicating a great accumulation of energy or stress in the initial jar; (4) that the origin is

seldom a *point*, but generally a line or narrow district, which may be many miles in length; and (5) that the subterranean stresses are not relieved by a single movement of the strata, but rather by a quick succession of movements, causing a series of jars, and it is such a *series* that causes an earthquake. The series lasts from a second or two to several minutes. The jars of a series quickly increase to a maximum of energy, and then more gradually become less energetic.

The redistribution of internal stresses following the movements of the strata which cause a great earthquake, generally results in lesser movements of other subterranean strata in the neighborhood, and thus originates minor earthquakes, which may affect the same region at irregular intervals for a year or more after the occurrence of the great earthquake.

The Transmission of Earthquake Shocks.—An elastic wave travels through rocks with wonderful rapidity; still its transmission occupies a certain amount of time. Hence, an earthquake shakes places which are near to the origin sooner than places successively more distant. The part of the earth's surface which is nearest to the site of the subterranean jar lies directly over it. Therefore, in any earthquake the district in which the shocks occur earliest is called its *epicentrum* (on the center). This is located at some approximately central part of the shaken region. At the boundary of the shaken region the earthquake occurs some seconds or minutes after the epicentrum is shaken.

The velocity of elastic waves is greater in compact solids than in those of looser texture. It is about four miles a second in steel, about two miles a second in compact granite, and but 800 to 1,000 feet a second in compact sand or clay. The different strata near the earth's surface vary greatly in compactness, but as the depth increases,

the weight of overlying rocks compacts all the strata, but especially the more porous and compressible, until, at the comparatively slight depth of a few thousand feet, all the strata attain a great and nearly uniform degree of compactness. Hence, the earth's crust may be divided into two layers or shells: (1) a comparatively thin outer shell of exceedingly various density, through which elastic waves travel at greatly differing velocities; and (2) a thick inner shell of great and approximately uniform compactness, through which the waves travel with a nearly uniform velocity, which is thought to exceed three miles a second.

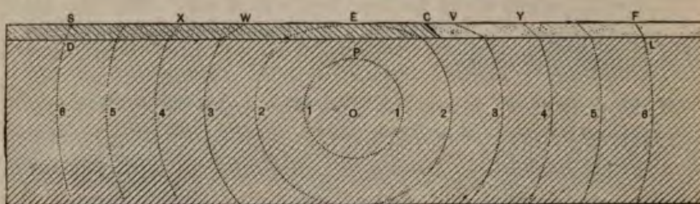


Fig. 112.

The diagram (Fig. 112) represents a section of the earth's crust. *SF* the surface, and *DL* the division (say at the depth of 1 mile) between the two shells. Suppose the outer shell to the left of *C* is more compact than to the right of *C*, and the inner shell is still more compact. Let *O*, at a depth of 5 or 6 miles, be the origin of an earthquake, and the spaces between adjacent curved lines the distance traveled by the elastic wave in one second of time. As the wave spreads and enlarges, it maintains a general spherical or spheroidal shape in the inner shell, but becomes flattened and otherwise deformed as it passes through the outer shell of varying compactness. In nature, the shape of the wave is much more irregular than represented, especially in the outer shell; and it is on account of these great irregularities of shape, speed, and effect resulting from the passage of the wave through the superficial strata, that it is so difficult to discover the laws of earthquakes from surface observations. The diagram indicates that the wave reaches the sur-

face first at the epicentrum E; that it then requires one second to spread to W and V; two seconds for it to reach X and Y, while the wave does not shake S and F until four seconds after E is shaken.

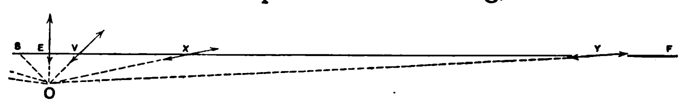
Energy.—Not only does the earthquake occur earliest at the epicentrum, but its energy is greatest in this locality. The energy is least at the boundary of the shaken area. The diagram (Fig. 112) renders this evident. The energy which causes the disturbance in every part of the shaken region was originally concentrated at O. It spreads from O in the elastic wave. As the wave enlarges, the energy is distributed over its increasing circumference, and the amount at any one point in the wave constantly diminishes; hence, the point E in the small circle 2, 2, receives more energy than the points X and Y in the larger circle 4, 4, and much more than the points S and F in the still larger circle 6, 6.

The distance to which an elastic wave is propagated depends (1) on the amount of energy at the origin, and (2) upon the compactness and uniformity of the strata. A jar occurring in the outer shell might, on account of its nearness to the surface, cause an exceedingly violent earthquake at and about the epicentrum, but on account of the rapid dissipation of energy in passing through strata of loose texture, the earthquake would probably affect but a small surface area. If the same amount of energy should cause a jar at a much greater depth, the epicentrum, being farther from the origin, would be less energetically shaken, but the elastic waves would spread faster and farther through the deep, compact strata, and might carry to considerable distances enough energy to penetrate the thin outer shell, and thus cause the shaking of a much more extensive surface region. It seems probable, however, that most jars in the inner shell are more energetic than those which occur in the outer shell, for it

must, in general, require a greater accumulation of energy to cause movement in deeply buried strata than in those pressed upon by a less weight of overlying rocks.

The subterranean explosions and the fracturing and fissuring of the strata, which frequently accompany volcanic eruptions, are often sufficiently energetic to cause violent earthquakes in the immediate vicinity of the volcano; but such earthquakes never affect a large region because the origin is at a comparatively slight depth.

Surface Effects of Earthquakes.—The vibration of rock molecules which constitutes an elastic wave consists chiefly of a minute forward movement in the direction the wave advances, and a minute backward movement toward the origin. Consequently, the earthquake at the epicentrum consists of an up-and-down shaking, while at other



S.F. = *Earths surface* E. = *Epicentrum*
O. = *Origin* V. X. & Y. = *Points successively more distant*
Double headed arrows = direction of vibration of rock molecules

Fig. 113.

places in the shaken region the movement becomes more and more horizontal as the distance from the epicentrum increases. This is made plain by Fig. 113, which also indicates that the epicentral area *s-v*, in which the principal movement is up and down, forms a very small part of the whole shaken area, its size increasing with the depth of the origin.

The boundary of this epicentral district can sometimes be located on the ground with considerable accuracy as inclosing the area where the relative violence of the earthquake has manifestly been greatest. When this can be done, it affords the best known method for calculating the depth of the origin.

Within the epicentral district the earthquake tends to throw surface objects upward. Men and heavy masses of rock have been thrown into the air, and large trees

have been uprooted and thrown upward. Foundations of brick or stone masonry under buildings in the epicentral district are sometimes actually crushed by the suddenness of the upthrust when the enormous energy of the elastic wave arrives at the surface beneath them, just as a *sudden* upward blow on a suspended mass of wax may crush and *indent* it, while if the same amount of energy had been applied more gradually, it would have simply moved the whole mass of wax without indenting it.

Without the epicentral district, the principal impulse of the earthquake is more nearly horizontal. Still there is some up-and-down movement, and this may impart a slight but yet sensible motion to the comparatively light surface strata, just as sensible motion was imparted to the clay cake on the end of the iron bar. This slight up-and-down movement imparted to adjacent parts of the ground in quick succession, as the earthquake spreads rapidly outward, throws the surface into an actual undulation or wave, similar to a water wave that spreads outward from an agitated point in the surface of a pond.

Cracks and Fissures in the Soil.—The passage of the crest of such an earth-wave or undulation often causes fissures many feet deep to open in the soil, which sometimes remain open, but more frequently open and close alternately as the crest and trough of successive undulations pass under them. The conduits of subterranean water are generally disarranged by such fissures, and thus the location of surface springs is frequently changed, temporarily or permanently, by an earthquake, while the underground pressures of the passing undulations often cause the ejection from the fissures of water, sand, and mud to a height of many feet.

Buildings are caused to rock or sway back and forth by the passage of such undulations, the oscillation being

greater in the upper part of the building than below, just as the part of a ship which oscillates through the greatest distance when a wave passes under the vessel, is the top of its masts. A very slight movement of this kind is sufficient to crack the walls of rigid buildings, and to occasion a swing at the top of high houses great enough to cause the downfall of chimneys or even of the walls themselves. Well-made frame buildings, on account of the greater play which they allow at the places where the various timbers are joined together, are not so apt to be destroyed by earthquakes as rigid brick or stone houses. It is by this quiet oscillation of buildings that many extensive earthquakes are recognized over by far the greater part of the shaken area, most or all of the "shocks" becoming so slight in the transmission to great distances that they are scarcely perceptible.

The surface violence of earthquakes varies greatly in closely adjacent localities, owing to the differences in texture of the superficial strata. The localities where earthquakes are apt to be least violent are those situated near the center of an extensive region underlaid to a *great depth* with strata of loose texture, for all but the most energetic waves are quenched in this loose material before reaching the surface; but if the depth of the loose material is only slight, the locality is apt to be more violently shaken than one on compact rock, for the elastic wave may impart to a thin and comparatively light layer of loose material at the surface, as it did to the clay cake on the iron bar, a sensible motion, which is apt to be sufficient to destroy the most substantial buildings.

Deep sounds or rumblings frequently accompany or follow earthquakes, especially in and about the epicentral district. They are caused by vibrations imparted to the air by such of the rock vibrations as are of the proper length and rapidity to excite in us the sensation of sound. The air transmits these vibrations to the ear precisely as it does those of the string of a violin, and the air vibrations become sensible as sound in both cases.

Scenes in Charleston after the Earthquake.

Sea Waves Caused by Earthquakes.—When the epicentrum of an earthquake occurs beneath the sea, the upward impulse of the sea bottom may upheave the overlying water and cause a series of sea waves, which spread in all directions to great distances with a velocity which increases with the depth of the water, but which, even in the deepest ocean, is not nearly so great as the velocity of an elastic wave through a compact solid. Hence, if the earthquake which causes the sea wave is felt at all on land, it is felt some time before the arrival of the sea wave.

In the deep open ocean these sea waves are so long and so low that their passage beneath a vessel is generally imperceptible; but in entering shoal water, as land is approached, the waves become shorter and higher, after the manner of the tide waves, and their arrival at the shore is indicated by the rapid rise of the water above its usual level. Such a rise of 50 to 100, or even 200 feet, has been known. The greatest waves are produced by an earthquake causing a very energetic disturbance in an epicentral district located not very far from the coast, and yet beneath deep water. These conditions are most likely to occur on the steeply sloping convex margin of the continental plateau, and hence great sea waves are more frequent on the abrupt Pacific coasts than on the more gently sloping Atlantic shores, though great waves inundated the steep coast of Portugal after the great Lisbon earthquake.

Among the earthquakes which have occurred in the United States, four are specially prominent on account of the great area over which they were felt.

In 1811 an earthquake shook the entire territory between western Texas and Washington City, and the Gulf of Mexico and the Great Lakes, an area of more than a million square miles. It was caused by subterranean movements which occasioned the settling to a depth of 15 or 20 feet of a large district about New Madrid, Mo., below the junction of the Ohio and Mississippi rivers. Portions of the sunken district, 20 miles or more in length, were afterward flooded by the river, and became Reelfoot Lake in north-western Tennessee, and Big Lake between Missouri and Arkansas.

In 1872 an earthquake was felt over the Pacific slope from Oregon far into Mexico, and from the coast eastward to Utah and New Mexico. The surface indication of the subterranean movements which caused this earthquake was the tilting and shifting of a great block of the earth's crust 40 miles long and one fourth of a mile wide in Owens Valley, Cal., at the east base of the Sierra Nevada. This block settled about 25 feet along its western side, and about 5 feet along its eastern side. Many houses in the town of Inyo, near the epicentral district, were destroyed, and several lives were lost.

In 1886 an earthquake occurred which shook the region from Wisconsin to Cuba and the Bermuda Islands, and from Maine to the mouth of the Mississippi, an area of nearly 3,000,000 square miles. Its epicentrum was about 15 miles north-west of Charleston, S. C. Few known earthquakes anywhere have shaken a larger area, and hence the jar which caused the Charleston earthquake must have been among the most energetic of which the world has record; and yet many earthquakes have been much more violent. Hence its origin must have been one of the most deeply buried. The boundary of its epicentral district was well marked, and from it the depth of the origin was calculated to be about 12 miles. Within the epicentral district was the little collection of frame buildings, called Summerville. This was terribly shaken, and a dozen or more of its wooden houses were wrecked. In Charleston almost all the brick buildings were severely injured, and a large number completely wrecked. Many chimneys were overthrown as far distant as Atlanta, Ga., (250 miles), Asheville, N. C., (230 miles), and Raleigh, N. C., (215 miles). Had the epicentrum occurred a few miles farther south-east, or had the city been underlaid by a less depth of loosely compacted strata, Charleston would probably have been laid in ruins, and the loss of life would have been vastly greater than it was.

In May, 1887, an earthquake shook the region between the Colorado and the Rio Grande from Utah almost as far south as the city of Mexico. Its epicentral district, in the Mexican state of Sonora, included the town of Babispe, which was entirely destroyed. The epicentral district was found to be traversed by a new fault 35 miles long, of which the vertical displacement averaged 8 feet.

CHAPTER XX.

VOLCANOES.

Bow thy heavens, O Lord, and come down: touch the mountains, and they shall smoke.—PSALM CXLIV: 5.

A volcano is essentially a collection of ducts or fissures in the earth, from which intensely hot gases and rocky material have been discharged. The rocky material discharged usually accumulates around the ducts into a more or less isolated and cone-shaped heap called a *volcanic cone*, which may reach an altitude of many thousand feet, and cover an area of hundreds or even thousands of square miles. The principal mouth, or vent, of a volcano usually occurs in a hollow, called the *crater*, near the summit of the cone.

Volcanic eruptions vary greatly in intensity at different times and places. A few volcanoes are constantly discharging matter; usually, however, volcanic activity is intermittent,—eruptions lasting days, weeks, or months, alternating with dormant periods, lasting years or even centuries, during which there is no discharge. Continuous eruptions, or those recurring at short intervals, are seldom very violent; violent eruptions generally succeed, and are followed by, proportionately long periods of rest. Eventually, after perhaps thousands of years of such constant or intermittent activity, the great heat beneath a vent subsides permanently, and the volcano becomes extinct.

The materials discharged in eruptions are chiefly melted rock or lava and steam. When the lava rises in the ducts, its entire mass seems to be permeated with steam, which escapes from it more or less explosively. Relatively small quantities of other gases are generated by the heat from various minerals in the lava, and, by their action upon each other and the surface rocks, frequently cause deposits of sulphur, alum, gypsum, salt, and other substances to accumulate about the volcanic vent. Some of these gases are combustible, and are ignited by the heat; but the flames are only feebly luminous, and never form a conspicuous feature of an eruption.

The lava is discharged both in streams and in fragments, the proportion discharged in either manner depending largely upon the violence of the eruption. In very quiet eruptions, the lava is discharged chiefly in streams, while in some very violent eruptions it is entirely ejected in fragments; usually, however, lava is ejected in both ways during an eruption.

The violence of an eruption depends to a great extent upon the fluidity of the lava and the abundance of its permeating steam. With stiff lava in the ducts, the steam, when abundant, escapes spasmodically with terrific explosions, hurling to prodigious heights and distances vast quantities of glowing lava masses, and blocks of rock torn from the crater or the sides of the duct. The lava masses are of various shapes and sizes, and, cooling in the air, fall as globular *bombs;* jagged and slag-like cinders or *scoriæ;* glassy and bubble-impregnated *pumice;* gravelly *lapelli;* sand; and the fine, glassy dust called *volcanic ashes.* Deluges of rain from the condensing steam falling on the cone transform the dust into a fine fluid mud, which hardens into a compact rock called *tuff,* while the larger fragments are cemented together into

volcanic *conglomerate*. The steam escapes more readily and continuously from very fluid lava; hence, a violent eruption of such lava seldom occurs. But even very fluid lava is viscous, like syrup, and the escaping vapors carry up from its surface long filaments, which, when cool, resemble spun glass. This is called Pele's Hair in Hawaii, where it is formed in great quantities.

The fluidity of lava depends largely upon its mineral composition. When composed largely of infusible silica it is called *trachytic* lava, which is never thoroughly melted, and is always stiff. When less silica is present, it is called *basaltic* lava. This melts more readily, becoming as fluid as melted glass, and is apt to resemble glass upon cooling rapidly.

Lava streams issue at a white heat either over the edge of the crater, or more frequently from fissures in the side of the cone, and flow rapidly at first. Very soon a cool, solid crust forms over a stream, which moves very slowly, while the interior, prevented by the non-conducting crust from cooling quickly, flows faster, and constantly bursts through the cool crust that rapidly forms on the front of the stream. The flow of the interior sometimes leaves long hollows or tunnels beneath the crust, but usually the slow advance and contraction of the cooling crust break it up into countless blocks which settle down into the cavities beneath (Fig. 114).

The crust of a lava stream is such a poor conductor that the interior may remain at a red heat for many months after its eruption, and during this time the whole mass may be imperceptibly advancing. Enormous volumes of steam escape through the crevices in the cool crust of a fresh lava stream from the hot interior, sometimes throwing up miniature cones. The steaming vents on a lava stream are called *spiracles* or *fumaroles*. The length of lava streams depends chiefly upon the amount of lava erupted and its liquidity. Streams from 1 to 5 miles long are very common, but the enormous outflows of very liquid lava in Hawaii and Iceland have reached distances of from 30 to 50 miles.

Fig. 114.—An old Lava Stream on Vesuvius.

General Shape of Cones.—The material ejected is deposited over a wide area, but in decreasing quantities as the distance from the vent increases; thus, the conical shaped heap or mountain is gradually built up by the deposits of successive eruptions. The steepness of volcanic cones varies greatly, and depends partly upon the average liquidity of the lava in its various eruptions. Cones built chiefly of fragmental material are apt to be steep, since this material will stand at a slope of about 35°. Outflows of stiff lava also produce steep slopes. Very fluent lava, on the contrary, is apt to produce flatter cones; those of Hawaii and Iceland have an inclination of less than 10°, while in many parts of the world, as in the western part of the United States, the peninsula of India, the plateau of Abyssinia, and elsewhere, tens of thousands of square miles are covered many hundreds or even thousands of feet deep under successive outflows of ancient basaltic lava in practically horizontal layers. These lavas must have

been very fluid at the time of their emission, since no cone at all seems to have been produced. It is even thought that they may have welled quietly up through numerous long fissures over the several regions without many of the phenomena characteristic of modern volcanoes.

The internal structure of many cones has been laid bare by prolonged erosion after the volcano has become extinct. The fragmental deposits and lava streams of successive eruptions give the cone an irregularly stratified structure, the strata having a general dip away from the central ducts. These inclined beds are intersected by

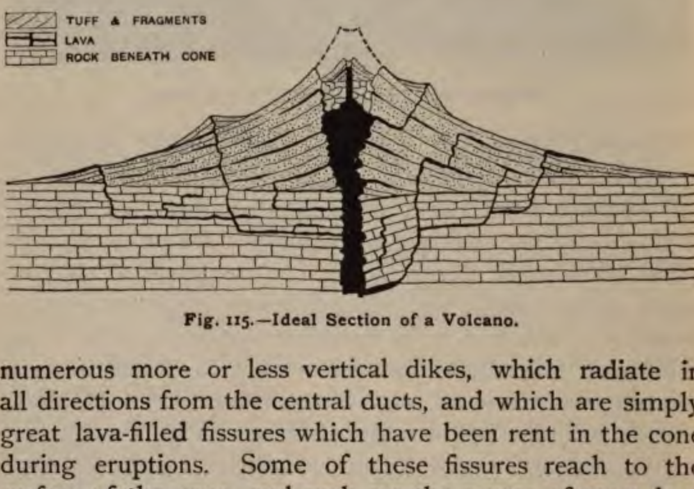


Fig. 115.—Ideal Section of a Volcano.

numerous more or less vertical dikes, which radiate in all directions from the central ducts, and which are simply great lava-filled fissures which have been rent in the cone during eruptions. Some of these fissures reach to the surface of the cone, and such are the source of most lava streams; others do not open through to the surface, and appear as dikes only after erosion has worn away the overlying beds. A great fissure in a large cone is often marked by a line of minor or *parasitic* cones, thrown up successively along its course as it opens. The great cone of Etna has more than 200 parasitic cones, some of them

Fig. 116.—Laccolite forming Mt. Hillers, Henry Mountains.

over 600 feet high. In some cases, the rocky platform beneath has subsided to a greater or less extent as the cone accumulated. In other cases, the ascent of stiff trachytic lava in the central ducts seems to have bent the adjacent strata upward, and very frequently it is found to have penetrated horizontally between strata, forming deeply buried horizontal sheets of great extent.

These intrusions of trachytic lava between deeply buried strata are not only very extensive but sometimes very thick, when they are called *laccolites*. Their formation sometimes pushes up the overlying strata to form great dome-like hills or mountains at the earth's surface. The Henry Mountains, an isolated group in southern Utah, seem to have been upheaved by such a subterranean intrusion of lava, which, instead of reaching the surface as an ordinary volcano, spread out between the strata at a depth of between 2 and 3 miles, forming 25 or more great circular laccolites or lava cakes, the largest of which is about 4 miles in diameter and 1¼ miles thick. The overlying strata, pushed up into domes by these laccolites, have been in places entirely removed by ages of subsequent erosion, thus uncovering portions of the laccolites and revealing the cause of the uplift (Fig. 116). In Colorado, New Mexico, and Arizona, as well as in foreign countries, trachytic lava in great masses has been partially uncovered by prolonged erosion; many of these masses are doubtless laccolites, and indicate that such subterranean intrusions are by no means exceptional.

Changes in the Crater.—Every eruption changes the shape or size of a cone. Minor fragmental eruptions increase its height and bulk, but great or violent eruptions generally decrease its height, for the whole top of a cone may be shattered and blown off in fragments by the violent explosions, or it may be engulfed when a copious discharge of lava drains away its subterranean liquid support. Thus, great eruptions often transform the upper part of a cone into a huge abyss, called a *caldera*, which may be several miles in diameter, and more or less completely surrounded by precipitous cliffs thousands of feet high. Minor eruptions build up a new cone within a caldera, which may fill and obliterate it before an eruption again occurs of sufficient energy to destroy the top of the cone.

The crater of Kilauea (Hawaiian Islands) is a caldera 3 miles long and 2 miles wide. It almost always contains pools of liquid lava. The pools constantly overflow; successive overflows, cooling, gradually build up the bottom of the pit, until suddenly, after an indefinite interval of years, subterranean fissures open, through which the lava pools drain away, and the bottom of the caldera sinks, while great slices often fall from the precipitous sides into the abyss and thus increase its area. Old craters and calderas often become filled with water. Such lakes are common in all volcanic districts. Lake Taupo, in New Zealand, is thought to occupy one of the largest calderas in the world. The lake is 20 miles in diameter, and is surrounded by cliffs 1,000 feet high. Crater Lake, in the Cascade Mountains of Oregon, occupies another caldera 7½ miles long and 5 miles wide. The lake is 2,000 feet deep, and is completely encircled by cliffs 1,000 to 2,000 feet high. From its surface an extinct cinder cone 600 feet high rises as an island, bearing a perfect crater in its summit.

Eruptions.—Violent eruptions are usually preceded by muffled noises and earth tremors or shocks, caused probably by the fracturing of subterranean strata. Then follow explosions which occasion heavy local earthquakes. The crater breaks up, and solid blocks and glowing lava fragments are scattered far and wide, while the steam escaping

at each explosion, rising rapidly and condensing, adds a great globular mass to the dust and cloud canopy forming above (page 40). This canopy reflects the glow of the liquid lava in the ducts, and, together with the rapid ascent of incandescent fragments, produces the illusion of brilliant tongues of flame issuing from the crater. The column rising from the crater often reaches a height of several miles, within which is generated electricity, manifested by incessant flashes of lightning and terrific peals of thunder. Rainbows and halos are produced by the play of light through the water globules of the condensing steam, while the violent local updraught in the atmosphere generally occasions terrific winds in the district surrounding the volcano. With an outflow of lava an eruption subsides, though sand and dust continue for some time to be discharged to great heights and in such quantities as often to exclude all daylight from a great extent of the surrounding country. Eventually the discharge of all solid matter ceases, but steam and gases continue for a long period to rise from crevices in the cone and from the lava streams. Quiet eruptions may or may not occasion earthquakes, and may consist simply of the issue of steaming lava streams from the side of the cone. This is usually preceded by a rise of lava into the crater, and an increased discharge of steam.

The enormous energy of volcanic action is most strikingly displayed in the infrequent but very violent eruptions. Thus, in a single night of 1815 the top was blown from Tomboro, in the Malay Archipelago, reducing its cone from a shapely peak 2 miles high to a mere stump, less than half as high, with a huge caldera in the top. The eruption of Krakatoa, in 1883, was another instance of excessively violent volcanic action. Its explosions were audible for 2,000 miles in all directions, or over $\frac{1}{15}$th of the earth's surface, and a perceptible layer of the dust ejected fell at all places within 1,000 miles of the volcano; while the finest dust and vapor, shot up 15 or 16 miles high, were generally distributed over the globe, causing,

while still suspended in the atmosphere, the peculiar red sunsets noticed in all parts of the world for months after the eruption (p. 104). The volcanoes of Hawaii often exude lava streams which cover 100 to 200 square miles to a depth of 100 feet or more; but they are discharged so quietly that the display of energy is not striking. Repeated outflows of this kind, however, during untold ages, have built up a great flat cone 6 miles high from the ocean floor, to form the lofty island which is half as large as New Jersey. This cone must contain material enough to cover the whole United States 50 feet deep, and the energy required to heap it up is probably as great in the aggregate as that displayed during the life of any violently active volcano in the world.

Gradual Decay of Volcanic Activity. — The cooling of the earth's crust beneath an old volcanic region is an exceedingly slow process. For ages after all other signs of activity have ceased, steam and volcanic gases continue to escape at some volcanoes from the numerous fissures. A volcano in this condition is said to be in the *solfatara* stage. Gradually, the heat in the superficial parts of the crust subsides until no longer great enough to convert all of the percolating water into steam, and the old volcanic region becomes a district of hot springs.

Most of the warm springs in the world, and nearly all the very hot ones, occur in or near volcanic formations, though frequently in localities where no volcanic eruption has taken place for hundreds, and probably for many thousands of years.

Geysers.—The hot springs of volcanic regions are characterized not only by their high temperature, but by the immense quantities of mineral matter, usually silica, which they bring to the surface and deposit over their neighborhood in fantastic and intricate forms. Often the deposit forms extensive terraces of silicious sinter through which the streams rise into deep, funnel-like basins. If the water enters such a basin slightly above its boiling temperature, the spring may become a *geyser* (spouter or gusher).

The water near the surface, chilled by the air, is kept beneath its boiling temperature, while the water below is kept from boiling by the pressure of that above. Thus, the lower water becomes superheated, and gradually heats the surface water, which at last begins to boil. This relieves the pressure on the water immediately below, which, being above its boiling point, vaporizes explosively, and forces into the air a cloud of steam and a jet of the overlying water. This considerable relief from pressure is followed by louder explosions in the still hotter water beneath, and the more violent discharge of water jets and steam clouds into the air. The explosions and discharges continue until the basin is emptied and the water in the conduits is chilled below its boiling point by exposure to the air. The eruption then ceases, and the water rises quietly in the basin until the conditions are suitable for another eruption. The eruptions of a geyser occur at more or less regular intervals of time, but these intervals vary in different geysers, from a few minutes to many hours or days. By the continued mineral deposit, the shape and dimensions of a basin may be so changed as to convert a hot spring into a geyser, or a geyser into an ordinary hot spring.

Geysers occur in many volcanic districts over the world. They are most numerous and powerful at the sources of the Missouri in Yellowstone Park, Wyoming; near Mount Hecla, in Iceland; and in the North Island of New Zealand; but are also found in Mexico, the West Indies, the Azores, Thibet, the Malay Archipelago, the Fiji Islands, and possibly other places. The so-called geysers of California and Nevada are violently boiling springs rather than true periodic geysers, though they are closely associated phenomena. In Yellowstone Park there are more than 3,000 hot or boiling springs, including 71 geysers, of which the most noted are: the Giantess, which throws jets 250 feet high, at intervals of several weeks; the Bee Hive, spouting 219 feet, at intervals of 14 to 16 hours; Grand Geyser, 200 feet, at intervals of 16 to 30 hours; the Giant and Castle geysers, spouting about 200 feet high, and Old Faithful (see frontispiece), which every hour throws up jets to a height of about 150 feet. Whenever hot springs occur in clay formations, the water in the basin is apt to become more or less muddy from repeated caving in of the banks. Sometimes the pool thus acquires a thick, porridge-like consistency, and if the temperature be high enough to cause the water to boil, the explosion of steam-bubbles beneath the surface scatters the mud about. Such mud springs are called *mud volcanoes*. They are common in all hot-spring districts.

Distribution.—The indications of past or present v canic action are found in all latitudes and longitudes, a at all elevations. They occur on the continents, and both the continental and oceanic islands, while several r corded submarine eruptions attest their occurrence up the sea bottom. Volcanic activity seems to have be present somewhere on the earth's surface throughout ge logical time, but has gradually shifted the site of activity to new areas during the long course of the worl history. The total number of localities in the world which are found indications of volcanic action, ancient modern, would reach tens of thousands. About 300 v canoes are known to be active. About one half of the occur on the continental islands lying south-east and ea of Asia, and extending from New Zealand to Alask Within this region, volcanism is at present more energet than elsewhere on the globe. About one fourth of t active volcanoes are distributed irregularly along the e vated western margin of the American main-land, fro Alaska to the Str. of Magellan. There are about active vents in North and Central America, and about along the Andes. A few have been discovered in ea Africa, and on islands along that coast. Thus, fully thr fourths of all active volcanoes known lie just within t convex or *generally rising* border of the continent plateau. Only one eighth of the world's active volcano occur elsewhere on the continental plateau, and these a found in widely separated groups. Three of these groups Iceland, with 13 active vents; the Lesser Antilles, with and the Canary Islands, with 3—occur in *rising localit* on the generally subsiding concave margin of the platea a fourth group of 7 vents occurs in a rising area on t margin of the deep Mediterranean depression, while t rest, 5 or 6 in number, are found along the norther


REGIONS OF VOLCANIC ACTION.
NEW ZEALAND
AUSTRALIA
EQUATOR
PACIFIC OCEAN
ASIA
INDIAN OCEAN
NORTH POLE
NORTH AMERICA
EUROPE
AFRICA
ATLANTIC OCEAN
SOUTH AMERICA
Drawn on the same projection as the map of Regions of Elevations & Depressions.
The Continental Plateau is enclosed by the darker blue shading.
=Present or recent action (crosses show known activity)
=Generally ancient (extinct) action; the lines connected where the activity survives to the present.
=Active volcanoes in the oceanic depressions.
=Extinct " " " " "

margin of the geologically recent highlands of Asia. The remaining eighth of all the active volcanoes are distributed along the great submarine ridges which traverse the oceanic depressions. There are about 20 active vents in the depression of the Pacific, 10 in that of the Atlantic, and 2 or 3 in that of the Indian Ocean, while there are at least 2 within the Antarctic Circle.

Fig. 117.—Volcanic Necks in western New Mexico.

Indications of former volcanic action which is now either dormant or extinct are also found in all the regions mentioned above, and in many other localities over the land areas, chiefly in highly tilted and disturbed strata, such as are frequent in mountain regions; in fact, almost every mountain range in the world has associated with it, either in its mass or near its base, vestiges of volcanic action. It is generally true that indications of very recently extinct action are more numerous toward the convex side of the continental plateau, while vestiges of very ancient and long extinct volcanism are more numerous on the concave side. Indications of very recent action are found throughout the West, and of very ancient volcanic action throughout the eastern part of the Union. In the Cascade Range are many great volcanic cones between 10,000 and 14,000 feet high. Some of them are still emitting

steam and gases. At Feather Lake, in northern California, a fresh lava stream 3¼ miles long and a mile wide occurs, and is said to have been erupted in 1850. Fresh lavas, possibly a century or two old, are found in Utah and Arizona. In western New Mexico are lava streams 24 miles long and 4 miles wide, which can not be many centuries old; but in the same neighborhood are the remains of much older lava streams, which in the tertiary era flooded this region from many vents. Prolonged erosion has completely removed most of this old lava cap, and also a great thickness of the strata beneath it, leaving, however, on the site of each vent an isolated hill or mountain composed of the hard lava which solidified in the duct when the volcanism subsided. Scores of such "volcanic necks," from 800 to 1,500 feet high, are found in that vicinity. (Fig. 117.) Indications of still older volcanic action are found in the tilted lava sheets which traverse the eastern part of the Union from Maine to South Carolina. The Palisades of the Hudson, and Mt. Tom and Mt. Holyoke, of Massachusetts, are such sheets. These sheets were erupted early in the mesozoic era, long before the Rocky Mountains were upheaved. The tilted lava sheets which form Keweenaw Point and the Gogebic Range south of Lake Superior, are still older. The eruption of these sheets took place before the Alleghanies were upheaved — in early paleozoic times.

Causes of Volcanic Action.—All active volcanoes seem to occur in regions which are rising. It is probable that the heat which melts subterranean rock masses into lava, and leads to its ejection, is but a peculiar manifestation of the same energy which causes the upheavals of the earth's crust. Whatever be the causes of these movements, it seems certain that the friction of the moving rock particles against each other would generate exceptionally intense heat at certain places within the rising mass. The heat in these localities may become great enough to liquefy the more fusible rocks at a comparatively slight depth, though not great enough to liquefy the less fusible surrounding rocks. Thus, a subterranean cavity, or vesicle, full of molten lava, is formed, which may be many miles in horizontal dimensions, and many hundred feet in vertical depth. When, owing to the pe-

culiarities in mineral composition which determined its fusibility, the molten mass is lighter, bulk for bulk, than the solid rocks above, the great weight of the latter causes them to sink down into the cavity, squeezing the molten lava upward into the fissures caused by the subsidence. If the difference in weight between the lava and the solid mass above is but slight, the lava may rise only part way to the surface, and spread out between the strata to form subterranean lava sheets or laccolites; but if the difference in weight is great enough, the lava is squeezed upward to the surface, to overflow and form a volcano.

Thus, steam is probably not an essential factor in bringing the lava up to the earth's surface, though all lava seems to be permeated with steam when it reaches the surface, and the *degree of violence* of volcanic eruptions probably depends upon the manner in which this steam escapes from lavas of different mineral composition, and from the same lava at different temperatures and pressures. It seems probable that the water percolating through all rocks is converted at some depth into steam by the subterranean heat, and as such is absorbed or *occluded* by the molten lava in very much greater quantity than the lava is able to retain when its temperature and pressure diminish as it rises toward the earth's surface. Hence, the excess of the absorbed steam escapes, or is *excluded*, more or less explosively, according to the viscosity of the lava, producing a more or less violent eruption. It is a somewhat similar *exclusion* of carbonic acid gas, absorbed by water under high pressure, that produces the effervescence of soda water when the pressure within the "fountain" is relieved, by opening the nozzle.

PART V.—WEATHER AND CLIMATE.

CHAPTER XXI.

WEATHER AND CLIMATE.

When it is evening, ye say, It will be fair weather: for the sky is red. And in the morning, It will be foul weather to day: for the sky is red and lowering.—MATTHEW XVI: 2, 3.

Weather is the condition of the atmosphere at any time and place with respect chiefly to its temperature, humidity, clearness or cloudiness, rain, fog, or snow, and wind.

Changes of Weather.—The weather is every-where constantly changing, owing to the diurnal and seasonal variations of temperature. But, in addition to these comparatively regular changes, others, much less regular, take place as a result of the passage of cyclonic winds or storms, which may quickly replace the air over any locality with other air having a very different temperature and humidity.

In the torrid zone cyclones seldom occur, excepting in the western part of the tropical oceans; and hence the weather-changes in that zone, depending principally upon the variations in the position of the sun, occur with great regularity, the same changes often taking place at the same hour, day after day, for weeks together, every year.

In temperate zones, cyclonic winds are much more common. Between latitudes 40° and 70°, where they are of most frequent occurrence, an endless procession of cyclones and anticyclones moves eastward. Though their general movement is easterly, the different whirls seldom move in *exactly* the same direction (see chart, page 91) or at the same rate of speed; hence, different ones pass over the same locality at irregular intervals. Each whirl produces variations of weather as it passes over a locality, which modify in a marked degree those regular variations due to the alterations in the relative position of the sun; and as the whirls arrive at irregular intervals, the weather-changes are as *irregular* in temperate latitudes as they are regular in equatorial regions.

Weather Probabilities.—From long observation of the paths traveled by cyclones and anticyclones under different circumstances, the officers of the United States Weather Bureau are enabled to estimate with some accuracy the course which any cyclone or anticyclone observed in or near the United States, will pursue during the ensuing 24 or 36 hours; and it is upon this estimate that the weather predictions are based which the Weather Bureau furnishes for publication throughout the Union every morning.

The use of the telegraph in weather prediction began with its extension over this country in 1844–48, but was first systematically done by Prof. Joseph Henry and Prof. J. P. Espy about 1850. It was begun in Europe in 1854, and after the war was revived by the Cincinnati Chamber of Commerce for mercantile purposes. From this followed the action of Congress authorizing storm and flood predictions to be made at first by the Signal Service of the Army, but at present by the Weather Bureau. The atmospheric pressure and the condition of the weather are carefully observed twice a day at the same moment of time in all parts of the country, and the results are telegraphed to the central office at Washington. Here the data are entered upon a map, the isobars drawn, and the successive positions

of cyclones and anticyclones, as they travel over the country, thus indicated. It has been found that the topography of the country, the sunshine, and the relative temperature and moisture in adjacent cyclones and anticyclones, modify the direction and speed of movement of each; but that in general the centers of cyclones move north-eastward over the United States, while anticyclones move south-eastward. Owing, however, to the ever-changing conditions in adjacent whirls, it is usually impossible to predict with any degree of accuracy, the course of any observed cyclone or anticyclone more than 24 or 36 hours in advance.

Since the wind whirls about the center of all cyclones in the same hemisphere in the same direction, the weather on corresponding sides of all cyclones is very similar, and the same is true of all anticyclones. Thus, in the northern hemisphere the winds in the eastern part of a cyclone come from the south, and are relatively warm; and as they advance into colder latitudes their vapor condenses into cloud, rain, or snow; while in the western part of cyclones the winds come from the north, are relatively cold, and as they enter warmer latitudes less condensation takes place. Hence, as a cyclone approaches a place from the west, relatively warm, cloudy, rainy, or snowy weather prevails; but as the center passes to eastward over the place, a change to relatively cold, clear weather takes place. Anticyclones, on account of the reversed direction of the whirl, have colder and clearer weather on their east than on their west sides; but as the air in an anticyclone is sinking, and hence becoming warmer, it frequently happens that little or no condensation into cloud or rain occurs on either of its sides.

The chart (Fig. 118) indicates the observed weather east of the Rocky Mountains one November morning. A large cyclone is central over Iowa (LOW). To the east of LOW the winds of the whirl blow from south or south-east; to the north of LOW, from east or north-east; to the west of LOW, from north or north-west; and to the south of LOW, from west or north-west. To the east of

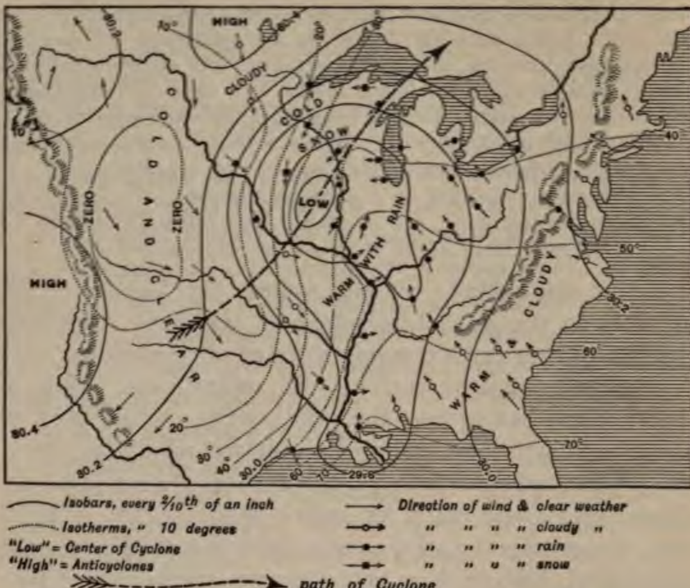


Fig. 118.

LOW, the southerly winds carry the warm air northward, so that the isotherm of 40° lies in the latitude of Cape Cod, Lake Erie, and southern Lake Michigan; to the west of LOW, the northerly winds carry the cold air south, so that this same isotherm lies near the coast of Texas. To the east of LOW, the warm air is constantly getting colder as it moves northward, and its vapor condenses, first into clouds near the south and east edge of the cyclone, then into rain as it reaches colder latitudes, and at last into snow as its temperature falls below the freezing point. Close to the west of LOW, the cold air from the north-west lowers the temperature, and the vapor still remaining in the winds from the north-east, is condensed into snow; but some distance to the west of LOW, cold and clear weather prevails. This general distribution of the various kinds of weather over the Central States was predicted 24 hours previous, when the center of the cyclone was observed to be in Indian Territory, near the feather end of the long dotted arrow; and its present position in Iowa enabled the Signal Service to predict the

distribution of weather which prevailed 24 hours later, when the cyclone center had advanced to the point end of this arrow. The decrease in pressure toward the extreme north-west corner of the chart indicates the approach of a cyclone from that direction. Experience with cyclones in that quarter teaches that they move south-east over the Rocky Mountains into Texas or Kansas, and thence north-east or east to the Great Lakes; and the kind of weather that their progress will cause in various localities may be predicted with considerable certainty at least 24 hours in advance.

Climate.—If the weather at any locality be carefully observed for a long time, it will be found to repeat itself more or less exactly, each year. Some years may be unusually hot or dry, and others may be exceptionally cold or wet; but when many years are compared, the general similarity in the succession of weather one year with another, can not fail to be remarked. This average annual succession of weather peculiar to any locality, constitutes its *climate*. Climate, like weather, embraces *all* meteorological phenomena; but the factors most important to agriculture and hygiene are: (1) the mean annual temperature, (2) the mean annual rain-fall, and (3) the distribution of sunshine, temperature, and rain-fall throughout the year. To the navigator another factor of equal importance is the direction and force of the wind.

The importance of the distribution of temperature and rain-fall through the year appears from a single example: San Francisco and Washington City have the same mean annual temperature (55°); yet the Washington summers are 18° hotter, and the winters 18° colder,—that is, the annual variation, or *range*, of temperature is 36° greater—than at San Francisco, where ice and snow in winter and oppressive heat in summer, are alike unknown. Sacramento, Cal., has only two thirds the rain-fall (22 inches) of Toledo, Ohio, (33 inches), and receives almost all of it in winter and spring, while at Toledo the rain-fall is nearly equal in each season, though slightly greater in summer and autumn.

The latitude of a place is the most important factor in connection with its supply of heat. In consequence of

the increasing obliquity of the sun's rays as the poles are approached, (page 50), the mean annual heating power of the sun's rays falling upon a given horizontal area, decreases from the equator to the poles in about the proportion indicated by the curved line in the diagram (Fig. 119), being but $\frac{4}{10}$ths as great at the poles as at the equator; and hence, in general, climates become colder as one journeys away from the equator.

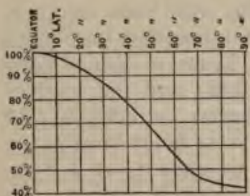


Fig. 119.

Effect of Latitude on Annual Range of Temperature.—All places receive heat by day and lose heat by night. At the equator the days and nights are always of equal length; hence, each night the temperature falls about as much as it rises during the day, and as the sun at noon is never very far north or south of the zenith, the heating power of its rays is nearly the same at all seasons. Therefore, the mean temperature of every day in the year is nearly the same; consequently, in equatorial regions there is no thermal division of the year (into winter and summer), but the climate over the whole torrid zone is characterized by great uniformity of temperature, the greatest variation being, in general, that between day and night. This is seldom more than 18°, and at some places near the equator it is much less.

At places not on the equator the lengths of the days and nights are constantly changing; for six months the days are longer than the nights, and for six months the nights are the longer. When the days are the longer, a place receives more heat by day than it loses during the short night, and thus accumulating heat, its mean temperature rises for six months; then, as the nights become the longer, it loses more heat than it receives, and its mean

daily temperature falls for six months. Now, the farther a place is from the equator, the greater is the difference between the length of its days and nights (page 51), and hence the greater is the variation of temperature during the year. In addition to this, the sun's rays, in middle and higher latitudes, are much more oblique, and their heating power is much less when the days are shortest than when longest; and this difference increases as the distance from the equator increases. Therefore, the climate in temperate and polar latitudes is characterized by a great variation, or range, of temperature during the year which increases, in general, as the latitude increases.

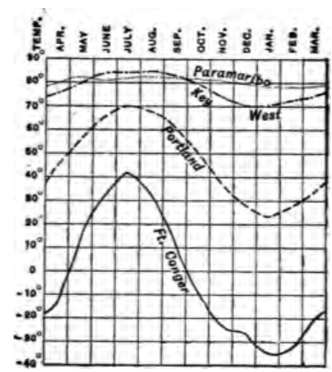


Fig. 120.

This is graphically indicated on the diagram (Fig. 120), which shows the average monthly mean temperatures at:

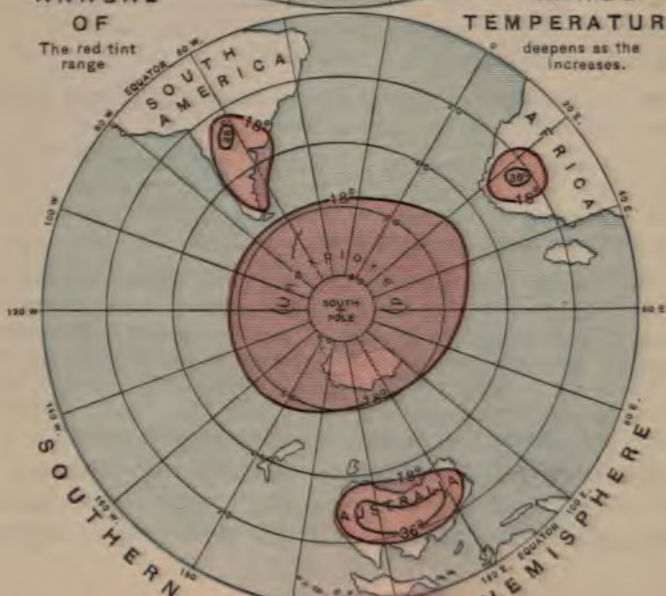
Paramaribo,	Guiana,	latitude	5¾°,	Range	4°.
Key West,	Florida,	"	24½°,	"	14°.
Portland,	Maine,	"	43¾°,	"	47°.
Fort Conger.	Arctic Regions,	"	81¾°,	"	76°.

The diagram also indicates that in summer, when the sun is nearly vertical over Key West, the temperature at that place is about 2° higher than in Guiana, nearer the equator. In winter, however, when the sun is over the southern tropic, the temperature at Key West is about 10° lower than at Paramaribo; hence, the *mean annual* temperature is lower at Key West than at places nearer the equator, though the summer temperature is higher.

Effect of Land and Water Surfaces on Climate.—It has been explained (page 64) that a water surface tends to equalize temperatures, while a land surface undergoes

ANNUAL RANGE OF TEMPERATURE

The red tint deepens as the range increases.



extremes of heat and cold during the year; and since the air acquires its temperature largely from the surface on which it rests, these peculiarities are impressed upon the climates of the oceans and the land respectively. That is, the climates of inland localities invariably have a greater annual range of temperature than those of coast regions, or of the open ocean in the same latitude.

Thus, the interior portion of the United States from El Paso, Texas, to North Dakota, has an annual range 25° to 55° greater than the Pacific coast, and 6° to 30° greater than the Atlantic coast in corresponding latitudes. The summers of the interior are *slightly* warmer, but the winters *much* colder, than those on the coasts or oceans; hence, the interior has a lower mean annual temperature, except in equatorial latitudes, where, as explained (page 62), the land is warmer than the sea at all seasons.

Continental and Oceanic Climates.—On account of the great influence of extensive land or water surfaces upon the variations of temperature, localities at which the annual temperature oscillates through a wide range are said to have a *continental climate*, while those where the range is small are said to have an *oceanic climate*.

The fitness of these names is rendered apparent by the chart, upon which the pink tint deepens as the range (between the mean temperatures of the hottest and coldest months) increases. The regions where the range is less than 18° have no pink tint, and are seen to embrace almost the entire ocean, except the polar seas, where the range is greater on account of the high latitude. Almost all the land surface, on the contrary, is tinted pink, and has a range greater than 18°. The range increases inland, being about 72° in the interior of northern America, and 108° in the more extensive grand division of Euro-Asia. The only parts of the land where the range is less than 18° are certain coast regions, where the influence of the neighboring ocean is great, and the equatorial regions of the land where, it has been seen, the mean temperature of all the months is nearly the same; but even here the range between *day and night* sometimes greatly exceeds 18° in the interior of the continents.

Climatic Differences of East and West Coasts.— In middle and higher latitudes (beyond 30° or 40°), a marked difference of climate exists in corresponding latitudes between the east and west coasts of the continents. This is caused chiefly by the relation between the continents and the direction of the winds. In these latitudes the general movement of the (antitrade) winds is from the west. In winter, however, on account of the difference of temperature between the land and sea air, a great anticyclone tends to form over the cold interior of the continents, and a great cyclone over the warmer oceans. The course of the air in passing out of the anticyclone into the cyclone is such, in the northern hemisphere, as to make winds from the north-west prevalent on the east side of continents, and from the south-east or south on the west side at this season (see Wind Chart, page 87, *January*). Hence, the eastern winters are much colder than the western, since the east side is flooded with dry air from the intensely cold northern part of the interior, while the west side is covered with air from the relatively warm southern part. Furthermore, the winters on the east side are relatively dry, since the air is advancing into lower latitudes and hence becoming warmer. On the west side, however, the winters are relatively moist, since the air is advancing into colder latitudes and constantly increasing in relative humidity. In summer, on the contrary, the relatively warmer air over the land tends to form a cyclone over the interior of the continents into which the surrounding air whirls, resulting in southerly winds on the east side, and northerly winds on the west side of the continents (see Wind Chart, page 87, *July*). Hence, the summers on the east side are relatively warm and moist, while those on the west side are relatively cool and dry. In general, the east side of continents in middle and

higher latitudes has a continental climate with abnormally low mean temperature, and the greatest rain-fall in summer; while the west side has a moderately oceanic climate with abnormally high mean temperature, and the greatest rain-fall in winter.

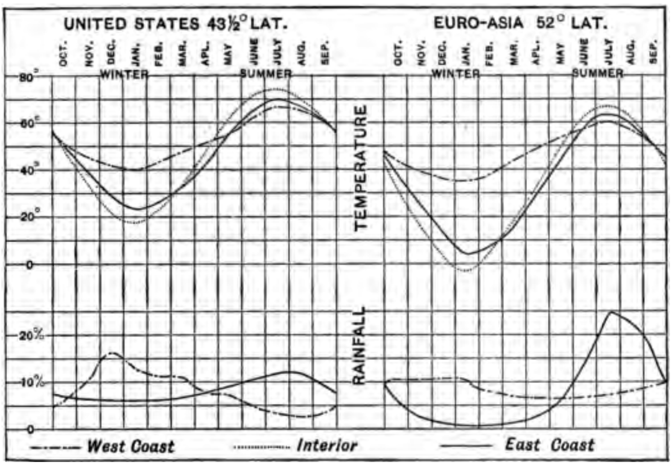


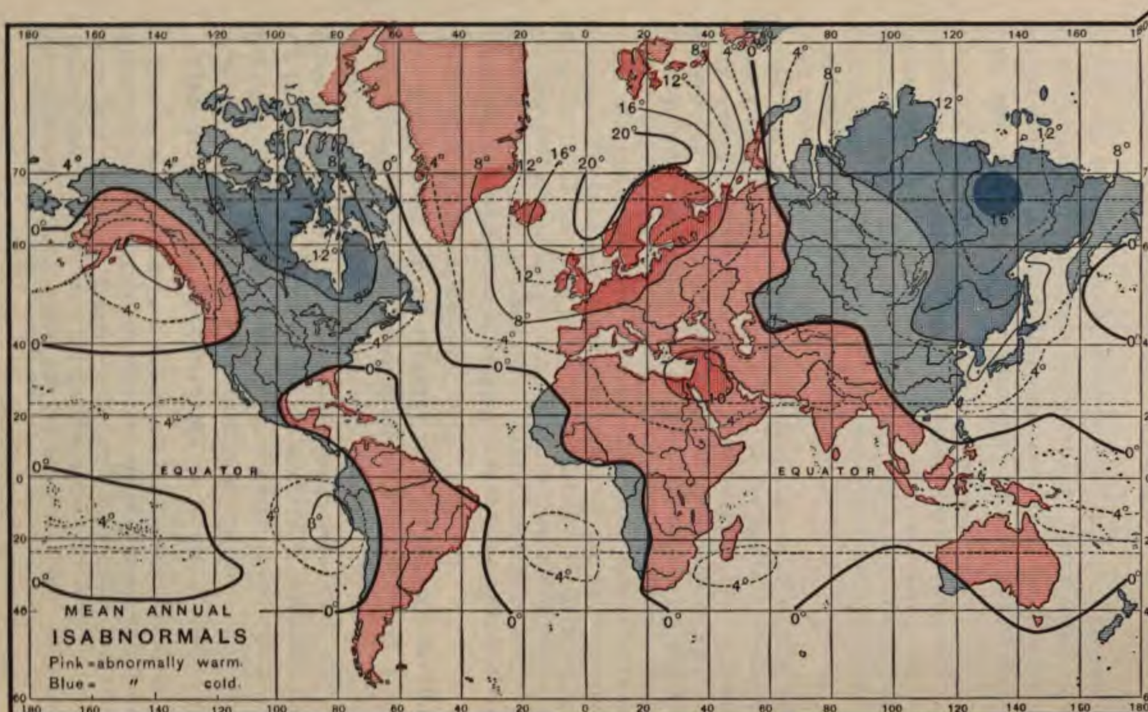
Fig. 121.

On the diagram (Fig. 121), this is well shown for middle latitudes in both North America and Euro-Asia. It is seen that while on the east coasts the range is not quite so great as in the interior, it is much greater than on the west coast, the summers being slightly warmer and the winters much colder; hence, the mean temperature is lower. The range is greater in Euro-Asia than in North America because the grand division is larger and the seasonal winds stronger. The rain-fall curves show that on the east side of both grand divisions most of the precipitation occurs in summer, while on the west side most of it occurs in winter. In the United States, the Rocky Mountains and the Colorado River roughly divide the east from the west side in the matter of winter and summer rain-fall. In latitude 60° N., the east coast of each grand division is about 20° colder than the west coast, and has a range about 35° greater. These differences

decrease southwardly and disappear within the tropics. This partly explains why the east coast of North America in middle and higher latitudes has a colder and more extreme climate than the opposite European shores in corresponding latitudes; thus, New York City has a mean temperature 8° less, and a range 26° greater, than the opposite coast of Portugal. In the same way, the climate of our north-west Pacific coast is more moderate than that of the opposite Asiatic coast. For the same general reason (direction of prevailing winds), there is a similar though small climatic difference between the east and west coasts of peninsulas or islands, or of great inland lakes. Thus, Milwaukee, on the west shore of Lake Michigan, has a mean temperature 2° lower, and a range 4½° greater, than Grand Haven, Mich., in the same latitude and only 80 miles distant, but on the east shore of the lake. The precipitation is 16% greater at Grand Haven, and is greatest in autumn rather than in summer, as at Milwaukee.

Ocean currents come from warmer or colder regions, and hence bring water abnormally warm or cold for the latitude; and this modifies the temperature of the overlying air. If this air is brought by wind to the land, then one may say that currents influence the climate of adjacent coasts. The currents on the west side of all oceans move *from* the equator in tropical latitudes and are relatively warm, while on the east side of the tropical oceans currents move *toward* the equator, and are relatively cool. Hence, the east coasts of the continents in equatorial regions have a warmer climate than west coasts. The reverse is the case in the higher latitudes, where cold currents move toward the equator in the western part of the oceans, and warm currents move from the equator in the eastern part (page 137).

Thus, the west coast of Africa, and the west coast of America from 40° N. to 40° S., are abnormally cool, while the east coasts of America from South Carolina to Cape Horn, and the whole east coasts of Africa and Australia have abnormally warm climates, owing to adjacent ocean currents. It is only opposite the equatorial calms, in which the counter-current carries warm water eastward,


MEAN ANNUAL
ISABNORMALS
Pink = abnormally warm.
Blue = " cold.
EQUATOR
EQUATOR

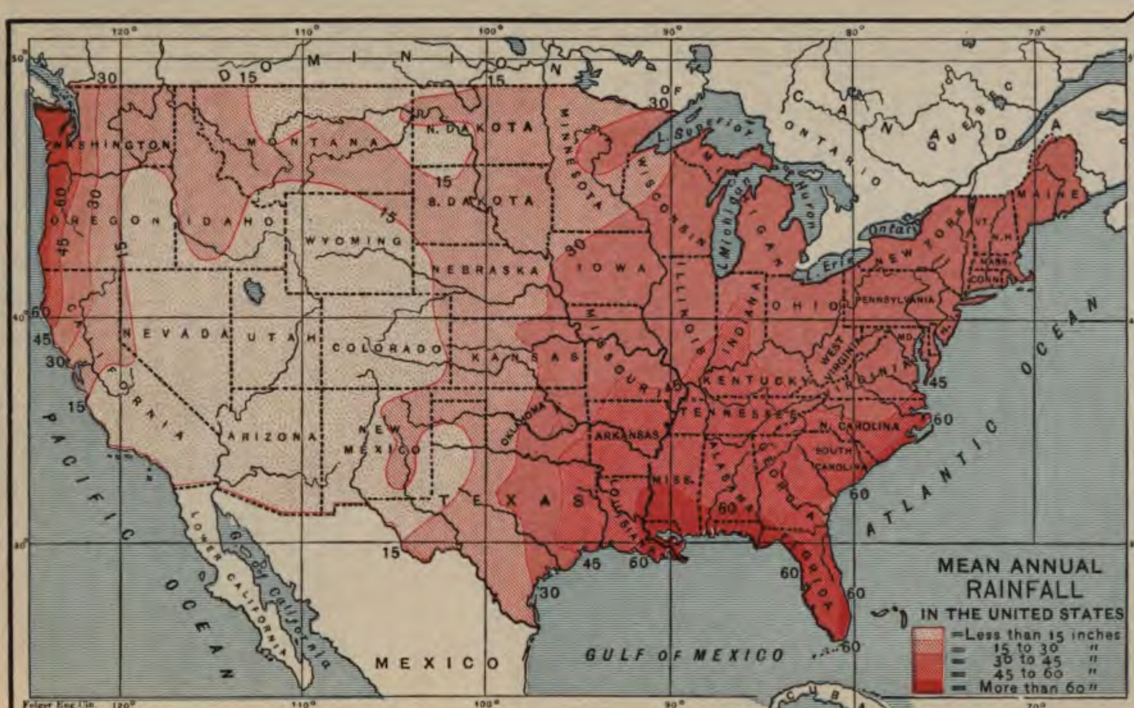
that inter-tropical west coasts are not relatively cool. In higher latitudes (above 40° N. and S.) the warm currents wash the west coasts, and aid the west winds slightly in producing a moderate climate, while the cold currents adjacent to the opposite east coasts exercise an equal influence in depressing the climatic temperature.

The amount of precipitation in coast regions also depends conjointly upon the direction of the winds and neighboring ocean currents. Warm currents—those flowing from lower latitudes—tend to produce a large precipitation, since the air over them is nearly saturated and is abnormally warm. It is therefore cooled and part of its vapor condenses, when transferred in any direction from over the current. Cold currents tend to prevent precipitation for contrary reasons.

The general distribution of rain-fall (see opposite chart and one on page 76), shows the connection between atmospheric precipitation, the temperature of the ocean currents, and the direction of the winds. It is seen that in the lower latitudes, to about the latitude of Cape Mendocino, Norfolk, Gibraltar, and Japan on the north, and Rio de la Plata, Cape of Good Hope, and south Australia on the south, the east sides of the continents enjoy east winds, are washed by abnormally warm currents, and receive the heaviest rain-fall. In higher latitudes, embracing the northern parts of North America and Euro-Asia, and the southern part of South America and Tasmania, we have west winds with warm currents off the west coasts, and the west sides of continents in these latitudes receive the heavy rain-fall.

The only places in tropical latitudes where heavy rain-fall occurs on west coasts are close to the equator, where the equatorial counter-current brings warm water against these coasts, and in India and Farther India, where the seasonal winds are very strong, and the configuration of these mountainous west coasts is peculiarly adapted to cool the moist south-west monsoon of summer.

In the torrid zone, where the great uniformity of temperature prevents a thermal division, the year is divided by the variation in the amount of rain-fall into a *wet season* and a *dry season.* Local peculiarities largely determine


MEAN ANNUAL
RAINFALL
IN THE UNITED STATES
=Less than 15 inches
15 to 30 "
30 to 45 "
45 to 60 "
More than 60"
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
MEXICO
DOMINION OF CANADA
ONTARIO
QUEBEC
LOWER CALIFORNIA
G. of California
CUBA
WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
ARIZONA
COLORADO
NEW MEXICO
N. DAKOTA
S. DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
TEXAS
MINNESOTA
IOWA
MISSOURI
ARKANSAS
LOUISIANA
WISCONSIN
ILLINOIS
MISS.
MICHIGAN
INDIANA
KENTUCKY
TENNESSEE
ALABAMA
GEORGIA
FLORIDA
OHIO
WEST VIRGINIA
VIRGINIA
N. CAROLINA
SOUTH CAROLINA
PENNSYLVANIA
NEW YORK
MD.
VT.
N.H.
MASS.
CONN.
MAINE
L. Superior
L. Michigan
L. Huron
L. Erie
Ontario
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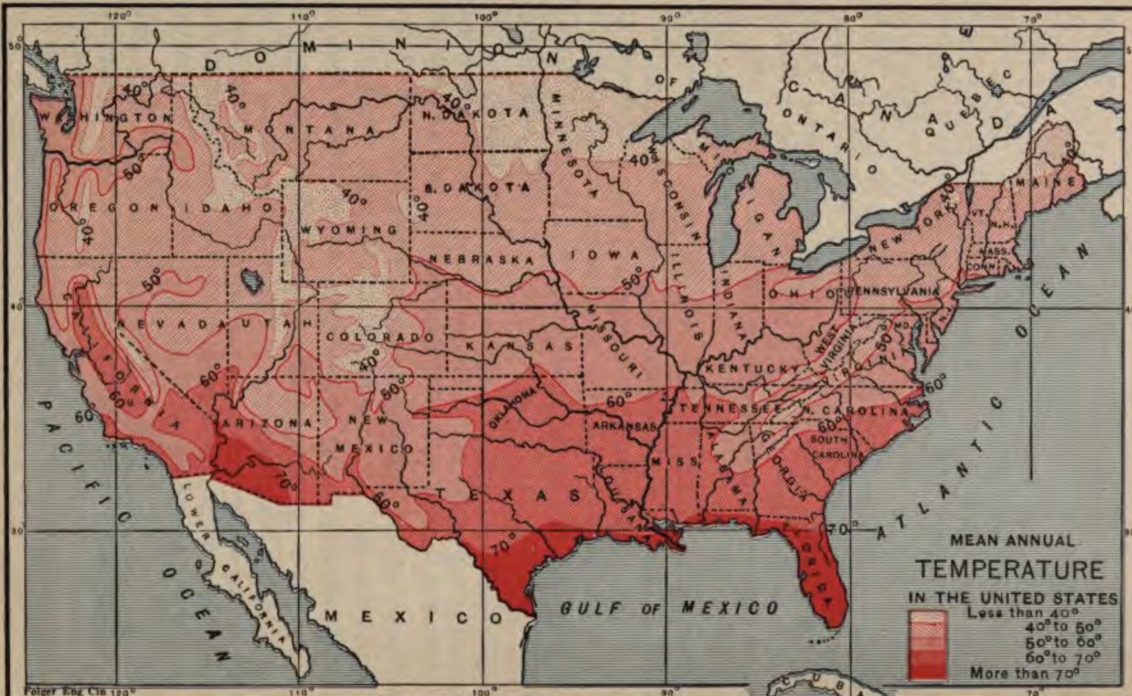
the time of occurrence of these seasons at different places, but in general the wet or rainy season occurs when the thermal equator crosses or lies in the vicinity of any locality; and this follows more or less closely the passage of the sun through the zenith of the locality. Near the thermal equator the motion of the air is upward; and as it cools in rising, its vapor condenses into clouds and rain.

Since the sun is twice annually in the zenith of all places between the tropics, there is a tendency toward two rainy and two dry seasons each year in the torrid zone; but, excepting near the equator where nearly six months intervene between the passages of the sun through the zenith, the two rainy seasons merge into one, thus dividing the year into one moderately long wet season and one very long dry season.

Influence of Elevation on Climate.—The climate of highlands every-where has certain general peculiarities which distinguish it from that of adjacent lowlands. Prominent among these are a *lower mean annual* temperature, and a *greater difference between the temperature of the air and that of the ground or surface objects.*

The air resting on highlands is less dense, is clearer, and contains less vapor than that resting on lowlands, and hence has fewer molecules to absorb the heat of the entering sunbeams by day or of the outward-passing earth radiations at night. Therefore, the highland air must in general be cooler than that resting on lowlands. This is well shown by the distribution of mean annual temperature of surface air in the United States, where the peculiar southward extension of the isotherm of 50° in the east and of 40° in the west is caused by the highlands of the Appalachian and Rocky mountains respectively. But for the very reason that the rays lose less of their heat in passing through highland air, the arrival or departure of these rays produces a greater heating or cooling effect upon the ground and surface objects than in lowlands; that is, the ground on the highlands, when exposed to the sun (by day or in summer), becomes hotter than the overlying air or than lowland ground. On the other hand, when not directly exposed to the sun (at night or in winter), the highland ground may become


MEAN ANNUAL
TEMPERATURE
IN THE UNITED STATES
Less than 40°
40° to 50°
50° to 60°
60° to 70°
More than 70°
D O M I N I O N O F C A N A D A
ONTARIO
QUEBEC
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
MEXICO
LOWER CALIFORNIA
CUBA
WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
ARIZONA
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MAINE
Folger Eng. Cin.

colder than either the overlying air or the lowland ground (p. 21). Vegetation fails on high mountains (even near the equator), not because the sun does not supply sufficient heat, but because the evaporation is too great, and the rare, dry air can not retain the heat near the earth's surface, and thus allow it to accumulate from day to day. In the lowlands of polar regions, on the contrary, vegetation does not thrive, partly because the sun's rays fall so obliquely that, though the dense lower air permits the heat to accumulate during several months of constant day, the aggregate is only sufficient to support a stunted vegetable life.

The exposure, or direction of slope, in hilly country has a great influence on the amount of heat imparted to the ground, and hence upon the climate. In the northern hemisphere the southern slopes receive the rays more perpendicularly, and for a longer time each day, and are hence warmer than the other slopes. In the southern hemisphere the northern slopes are the warmest. The higher temperature of the ground affects the overlying air, and makes the climate more moderate. Therefore, other things being equal, the lower limit of perpetual snow, and the higher limit of vegetation, lie at a greater height on the south than on the north slopes of mountains in our hemisphere.

The rate at which the air becomes cooler as the observer ascends, varies at different places, and at different times at the same place. The general average is about 1° Fahr. for each 300 to 350 feet of elevation on a slope whose acclivity is quite steep, as on a mountain side, but it is sometimes as rapid as 1° for every 200 feet, and sometimes as slow as 1° for every 500 feet. The rate is generally most rapid in summer, and on the warm side of a mountain. The rate is much slower on gentle acclivities than upon steep slopes. On the ordinary slopes of non-mountainous regions, as the great Mississippi Valley, the average rate is about 1° for each 450 feet of ascent.

Peculiarities of vertical distribution of temperature in hilly regions. During calm, clear nights, especially in winter, in middle and higher latitudes, it is observed that up to a certain height the air in valleys is colder than that on the slopes of surrounding eminences. Over open plains it has also been observed that the temperature during calm, clear nights *increases* with elevation. This increase of temperature extends at least to a height of 150 feet, and is most rapid in the lowest layers of air, where it may attain a rate of 1° in 5 feet, or even more. Thus, on frosty nights the tree-tops frequently remain unharmed, while the lower foliage and herbage are frozen.

The earth cools quickly on clear nights by radiating its heat through the overlying air. The air cools much less except where dusty or damp enough to have effective radiating power. Thus, the lower air is chilled by contact with the colder earth. On valley slopes the cooled and hence heavy surface air creeps down to the lowest ground, where it accumulates, lifting up the relatively warm air that it finds there. Accordingly, there is a climatic tendency toward warmer nights on slopes and hill-tops than in adjacent valleys. In latitudes where frosts, though infrequent, sometimes occur, this peculiarity is of great importance to the agriculturist, since the frosts, though occurring in the valleys, may never occur on the higher grounds. A region called the Thermal Belt, in the Appalachian Range, is thus specially favored.

Mountains tend to produce condensation of atmospheric vapor in all parts of the world, since the lower and moister air-currents are compelled to ascend in crossing a mountain range, and are thus cooled by expansion. Hence, mountain slopes to a certain height usually have a moister climate, that is, they have more clouds and rain, than the surrounding lowlands. Thus, in the plateau region of the West, many of the mountain ranges and higher *mesas* have a sufficient rain-fall to support quite a heavy growth of forest, while on the lower general surface of

the country, the rain-fall is so slight that prairie grass, sage-brush, and cactus are the only forms of vegetation, except along the streams that carry off the surplus rain-fall of the mountains. Even in the center of the intensely dry desert of Sahara, the higher mountain regions of Asben and Tibesti have a regular summer rain-fall.

Mountain ranges have a moist side and a dry side when they trend more or less directly across the direction of the prevailing winds. In the torrid zone, where easterly winds prevail, the east slope is usually the moist side,—as, for instance, the American Cordilleras from Mexico to northern Chile. In higher latitudes the west side of mountain ranges usually receives the greatest rain-fall,—as, for examples, the Cascade Range in Oregon and Washington and the Andes of southern Chile. Mountains whose trend is nearly parallel with the course of the wind, as the Appalachians and the Alps, have no well marked wet and dry sides.

In crossing a mountain range, the air loses by condensation on the windward slopes all the vapor it contains in excess of the amount which saturates it at the lowest temperature it attains when near the crest. In gradually sinking on the further, or *lee*, side of the mountain, the air is mechanically warmed, and hence its relative humidity decreases. This not only produces an excessively dry climate, but operates, also, to raise the mean, and increase the range of temperature on the lee side of the mountain, for the dry air and cloudless sky favor intense heating of the earth's surface by day, and rapid cooling by radiation at night, while on the windward side the rising air favors the formation of clouds and mists, which prevent intense heating of the earth by day, or extreme cooling by night.

PART VI.—LIFE.

CHAPTER XXII.

THE VARIOUS FORMS OF LIFE.

My substance was not hid from thee, when I was made in secret, and curiously wrought in the lowest parts of the earth. Thine eyes did see my substance, yet being unperfect; and in thy book all my members were written, which in continuance were fashioned, when as yet there was none of them.—PSALM CXXXIX: 15, 16.

Life is a mysterious and temporary manifestation in a peculiar kind of matter. This kind of matter is called *protoplasm*. The chemical composition of this substance is very imperfectly understood, but it is known to consist chiefly of carbon, oxygen, hydrogen, nitrogen, and sulphur, in various combinations, which differ somewhat in different kinds of protoplasm. But in all kinds, certain highly complex compounds of these substances, called *proteids*, are practically identical, and only matter in which these proteids are present is known to manifest the properties of life.

All matter in the living state is closely associated with lifeless matter in the same body or structure; thus, the fat, parts of the hair, nails, and blood, most of the horns or shells of living animals, and the bark, solid wood, and sap of living plants, are composed of matter in a perfectly lifeless condition. Science has never discovered what causes this wonderful difference of condition in matter, but so far as we know, the living state is never assumed except under the influence of existing living matter, which seems to infect lifeless protoplasm, and in some way causes it to assume the living state.

Living matter is distinguished from lifeless matter (1) by its power of repairing its waste, and of growth, and (2) by its power of reproduction. While a mass of matter is in the living state, portions of it are constantly dying and being thrown off, but the living portion continually repairs the loss by a process called *intus-susception*. This consists in manufacturing appropriate kinds of new particles, and fitting them into the interstices between those present, throughout the whole mass. If this process exceeds the loss, the living mass increases in size, or *grows*. In this respect, living matter differs widely from lifeless matter, which grows, if at all, only by the addition of particles to its surfaces. Living matter not only repairs its waste, and grows, but under certain circumstances detaches from itself masses of living matter which are endowed with all the properties of growth and reproduction possessed by the parent mass.

Organisms.—Living bodies of all but the lowest forms are composed of unlike parts, each capable of performing different functions essential to the life of the whole body. These unlike parts, such as the stomach, heart, limbs, etc., in animals, and roots, stem, leaves, etc., in plants, are called *organs*, and the whole body is called an *organism* because it possesses them; while lifeless protoplasm is frequently called *organic matter*, because, so far as known, it has invariably been produced in living bodies.

Cells.—All organisms exist at first as a minute mass

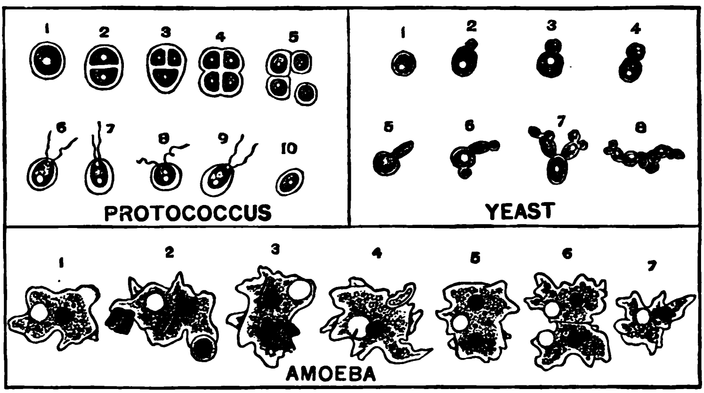
Fig. 122.

of protoplasm called the *germ-cell* (Fig. 122), forming part of the body of the parent, from which it becomes detached when the new organism has reached the proper stage of its development. The protoplasm of the germ-cell (*p*) is a transparent, jelly-like mass resembling white of egg, and part of it is usually gathered into a darker,

rounded *nucleus* (*n*), while the whole may or may not be enveloped in a membrane or sack of soft, lifeless material forming the *cell-wall* (*m*). When sufficiently magnified, the living protoplasm is seen to be always in motion, regular currents traversing its mass in more or less definite directions.

The simplest forms of life are organisms similar to the germ-cell, leading an independent existence, and reproducing similar forms by simply dividing into two or

Fig. 123.—Various Stages in the life of



more similar masses of protoplasm. Such simple yet complete organisms are the *Protococcus* and common *Yeast* plants, and the *Amœba* animalcule.

In all higher forms of life, the germ-cell develops by subdivision, or *segmentation,* through two, four, eight, sixteen, etc., into a great number of nucleated cells of protoplasm within the original cell-wall, which finally disappears. To this point the new cells closely resemble each other, being all nearly spherical, or varying from that form only by their pressure against one another. But

the further development of the organism is still more wonderful. New cells continue to be formed by segmentation, but the cells in different parts of the mass begin to surround themselves with cell-walls of lifeless matter, and to adapt themselves for the various kinds of work they have to do, by gradual *differentiation*; that is, assuming different shapes and structures. In many parts of the organism the protoplasm may nearly or entirely disappear in the production of cell-walls, thus producing a lifeless but solid or cellular portion of the organism, as the woody part of plants, and the bones and outer skin of animals. By continued segmentation and differentiation of the originally similar cells, the very dissimilar organs of the organism are finally formed, and each organ, when fully developed, is thus entirely composed of variously modified cells of living protoplasm, separated by more or less cellular walls of lifeless matter of various thickness, shape, and substance.

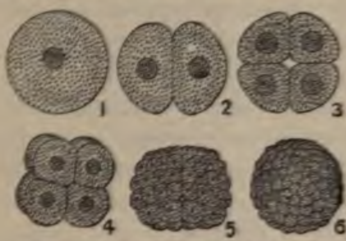


Fig. 124.—Segmentation of a Cell.

Respiration.—The development and growth of every organism as a whole is thus the result of the death and destruction of portions of its protoplasm. The general process by which this destruction is accomplished is the same in all organisms; they all exhibit the phenomenon of *respiration*, or breathing. Land organisms inhale atmospheric oxygen directly, while aquatic organisms inhale that which is dissolved in the water. The strong chemical affinity of oxygen for all other elements enables it to decompose the complex protoplasmic substances of the organism and form simpler and more stable compounds,

organic energy and heat being liberated by the change. One of the stable compounds is carbonic acid, which is largely *expired*, or breathed out, by all organisms. Thus, respiration is directly a destructive process, since it results in the killing and removing of portions of the organism.

Animal and Vegetable Kingdoms.—The material with which the loss, occasioned by respiration, is continually repaired, is manufactured from the *food* of the organism, the process being called *nutrition;* and since it consists of the conversion of lifeless food into living protoplasm, it is a constructive process, and therefore directly opposed to respiration. It is in connection with nutrition that the essential difference between plants and animals occurs. Since all living protoplasm contains the proteid combinations of carbon, oxygen, hydrogen, nitrogen, etc., the food of all organisms must contain these substances; but plants alone are able to manufacture the complex proteids out of simpler and more stable combinations of these elements, while animals require food in which the proteids exist already manufactured. Hence, the animal kingdom depends absolutely upon the vegetable kingdom for its food.

All *green* plants, which form by far the larger portion of the vegetable kingdom, can manufacture their food only in the sunlight (direct or diffused), and these plants obtain their food chiefly from two sources: carbon they obtain mostly from the carbonic acid in the air, through minute mouths (stomata) in the under side of the leaf; hydrogen and oxygen are derived chiefly from the water absorbed by the roots, though plants, like animals, also obtain oxygen by respiration from the atmosphere; nitrogen, sulphur, and other elements are derived chiefly as various salts dissolved in the water. By the aid of the kinetic energy in the sunlight, these *green* plants are enabled to decompose the water and carbonic acid, returning to the atmosphere part of the oxygen thus disengaged, but uniting the hydrogen and carbon with the rest of the oxygen to form a *carbohydrate*—starch. Sooner or later this is changed into a kind of

sugar (glucose), and, dissolved in the sap, is transferred to the point where new protoplasm is needed. Here, in some unknown way, it unites with the nitrogen and sulphur to form a proteid, and the newly made protoplasm becomes endowed with the properties of life. A few plants, as the fungi, bacteria, and common yeast-plant, do not require sunlight, but can live in darkness. These plants, like animals, require *organic* food; but, unlike animals, can manufacture proteids, if only a carbohydrate is present in their food. In this respect these organisms occupy an intermediate position between the animal and vegetable kingdoms. In almost all *animals* the region where nutrition occurs is completely and more or less directly inclosed by layers of cell-walls or membranes, but the proteids in food are *indiffusible;* that is, unable to pass through a membrane. Hence, the food has to be made diffusible before it can enter the system. It is to effect this preparatory change in the food, called *digestion*, that animals require a stomach, which is essentially a more or less complicated pouch formed by the infolding of the outer surface of the body. Thus, it is only after the digested food has passed through the walls of the stomach that it really enters the body. Plants, which manufacture the proteids within themselves, and some of the lowest animals, which, being minute naked masses of protoplasm, can receive their food by simply flowing over and enveloping it, of course require no stomach.

Two great laws of the organic world have been established from prolonged observation of living things: 1st, The *Law of Heredity; organisms reproduce others, which at maturity closely resemble their parents.* Though the resemblance is close, the likeness is never exact, and this leads, 2d, to the *Law of Adaptation; all organisms possess, in greater or less degree, the power to adapt themselves to gradual changes in their surroundings, or environment.*

It is a well known fact that family resemblances may generally be traced from one generation to another, but no two human beings are so exactly alike in all particulars that intimate friends can not distinguish certain differences. The same is true of all animals and plants: there is a close resemblance running through the various families, but no two organisms are exactly alike, though people generally are not sufficiently well acquainted with them to recognize at once individual peculiarities. The power of adaptation is illustrated

not only by the alteration in the appearance of plants and in the quality of the fur of many animals as the seasons change, but by the alteration in the skin and muscles of men and women which follows certain changes in their mode of living, as from an indoor, inactive life, to one of hard manual labor and exposure to the sun and elements.

The environment of an organism embraces every thing outside of itself that affects in any way the conditions of its existence. It embraces (1) all the factors that influence the food supply of the organism; (2) all the factors of climate; (3) all the factors that determine the presence or absence of other plants or animals that interfere with or promote the well-being of the organism; and (4) every thing that modifies any one of these factors. It is inconceivable that all these factors can ever be exactly alike at two different localities or at two different times. Hence, every organism has a different environment which is constantly changing to a greater or less extent, and the constant adaptation of an organism to its special environment probably accounts for its individual peculiarities.

Classification.—The grouping of organisms according to the degree of similarity in structure or function of their corresponding parts, constitutes *classification.* The first and broadest grouping of living things is into the vegetable and animal kingdoms. Each kingdom is then divided into several smaller groups, and these into others, which in turn are subdivided again and again. Each of the two largest divisions embraces organisms which are widely dissimilar in almost every respect excepting *mode of nutrition,* while each of the successively smaller groups is characterized by a greater and greater number of similarities between the organisms of which it is composed, until, in the smallest groups, of which there may be a million or more, all the individual organisms of each group, while not exactly alike, resemble each other so closely in structure

and function that they are said to constitute a single kind, or *species*, of plants or animals. Thus, there are a number of varieties of apples, and yet they are all sufficiently similar to be classed as a single species of the vegetable kingdom; and in the same way all chickens, though no two are *exactly* alike, are essentially similar, and are classed as a single species of the animal kingdom.

The characteristic similarities which determine some of the larger groupings and subgroupings of the organic world are given below, the groups embracing the simplest or lowest forms of vegetable and animal life respectively being placed first, and those containing the most complex or highly organized forms being placed last.

VEGETABLE KINGDOM,

all organisms able to manufacture the complex proteids.

Fig. 125.

Fig. 126.

Fig. 127.

a. CRYPTOGAMIA (*hidden seeds*). All flowerless plants. Subdivided into:

1. **Protophytes** (*first plants*). Simplest and lowest plants. Generally microscopic; either single cells or an association of cells without mutual dependence, as the *diatoms, moulds, bacteria, yeast,* etc. (Fig. 123).

2. **Thallogens** (*shoot growers*). Many cells, but without differentiation into stem and leaf; growing horizontally in spreading shoots or fronds, as the *algæ*, or sea-weeds; *fungi*, or toad-stools (Fig. 125); and the *lichens*.

3. **Bryogens** (*moss growers*). Cells differentiated into root, stem, and leaf, but no woody material; showing tendency to grow upward rather than horizontally, as the *liverworts* and *mosses* (Fig. 126).

4. **Acrogens** (*highest growers*). Cells differentiated more completely, the stem and leaves containing vascular, *woody* fibers; showing strong tendency to grow upward, as the *ferns* (Figs. 127, 129).

b. PHENOGAMIA (*visible seeds*). All flowering plants. Subdivided into:

1. **Gymnosperms** (*naked seeds*). Flowering plants which do not inclose their seeds in seed-vessels. The

group is subdivided into the (*a*) *cycads* (palm ferns, Fig. 128), (*b*) *conifers* (pines, firs, spruces, larches, cypresses, cedars, etc.), and (*c*) *gnetums*.

2. **Angiosperms** (*seed-vessels*). Flowering plants which inclose their seeds in seed-vessels. The group is subdivided into (*a*) *monocotyledons* (single lobed), which first develop a single seed leaf, or lobe, and are characterized by leaves having parallel veins; by three-petaled flowers; and by the absence of a distinct pith and lines of annual growth in the stem, as the *rushes, grasses*, (cereals, corn, cane, etc.), *lilies, bananas*, and *true palms* (Fig. 130); (*b*) *dicotyledons* (double lobed), which first develop a pair or more of seed leaves, or lobes, and are characterized by leaves having netted veins; and by the division of the stem into a central pith, an outside bark, and a series of concentric layers of wood between them, an additional layer of wood being added beneath the bark by each season's growth. This group includes most *garden vegetables, fruit-trees, and hard-wood forest trees*. It is subdivided into: (*a*) *monochlamyds* (single cloaks), or plants whose flowers consist of but a single whorl of leaves (the *calyx*), embracing the catkin-bearing plants, as willows, poplars, beeches, oaks, elms, laurels, hemp, hops, etc.; and (*b*) *dichlamyds* (double cloaks) or plants whose flowers consist of a double whorl of leaves (the *calyx* and *corolla*). This subdivision embraces most garden vegetables, cultivated flowers, fruit-trees, the locust, ash, elder, etc.

Fig. 128.

Fig. 129.

Fig. 130.

ANIMAL KINGDOM,

all organisms requiring proteid food.

1. **Protozoa** (*first life*). The simplest animals; mostly microscopic; consisting of a single cell, with or without nucleus; no stomach or organs, as the *amœba* (Fig. 123) and other animalcules, the *radiolarians* and *foramenifers* found in the oceanic oozes, *infusorians*, etc.

2. **Porifera** (*pore bearers*). Animals having many cells but no special organs. These animals are traversed by many pores, or cavities, which serve the purpose of a simple stomach. Though possessing no fixed symmetry of form, most of these animals secrete a stony or horny substance from their food, which serves the purpose of an irregular frame-work or skeleton. Such animals are the *sponges* (Fig. 131).

Fig. 131.

3. **Cœlenterata** (*hollow stomached*). Animals possessing a single, distinct stomach-cavity, with a body-cavity extending off from it. In this cavity or elsewhere several distinct organs appear; a more or less distinct symmetry of form, similar parts of the body being usually arranged around a center, like the spokes of a wheel around the hub. Such animals are the *hydras; medusæ*, or jelly-fishes (Fig. 132); and the *corals* (Fig. 68).

4. **Echinodermata** (*spiny or rough skinned*), having true stomach, separate from another body-cavity, containing organs answering to a heart and nervous system; radial symmetry like the preceding, but each ray usually consists of two similar halves, placed side by side (bilateral symmetry). Such are the *crinoids, star-fishes, sea-urchins* (Fig. 133), and *sea-cucumbers*.

Fig. 132.

5. **Vermes** (*worms*). Lowest animals possessing clearly bilateral symmetry; stomach divided into various special parts; body composed of a series of rings or segments; distinct head containing nervous centers (ganglia), such as the common *angle-worm*.

Fig. 133.

6. **Mollusca** (*soft*). Soft, unsegmented bodies, bilaterally symmetrical, enveloped by a leathery mantle, which usually develops a hard shell-covering, or external skeleton; a symmetrical nervous system, consisting of several connected nerve

bunches, or ganglia. Such are the *clams*, *oysters*, *muscles*, and *snails* (Fig. 134), *conchs*, *cuttle-fishes*, the *nautilus*, etc.

7. **Arthropoda** (*jointed feet*). Bilaterally symmetrical bodies composed of a series of rings or segments, each of which bears a pair of jointed appendages, or limbs; a well developed and symmetrical nervous system of many connected ganglia. The lower arthropoda are the *crustaceans*—barnacles, lobsters, (Fig. 135), crabs, etc. The higher are the *insecta*, or insects, as *spiders*, *myriapods*, *grasshoppers*, *beetles*, *flies*, *moths*, *butterflies*, *bees*, *wasps*, *ants*, etc.

Fig. 134.

(8) **Vertebrata** (*flexible*). Animals possessing a flexible backbone and an internal skeleton (see Fig. 146); a true brain in the head (see Fig. 148); a spinal nerve cord; and a more or less highly specialized nervous system.

Fig. 135.

The subdivisions of this, the highest of the primary groups of animals, are (*a*) *fishes*, (*b*) *amphibians*, (frogs, toads, etc.), (*c*) *reptiles*, (snakes, lizards, etc.), (*d*) *birds*, and (*e*) *mammals* (the breast), or animals which feed their young from the breast. The highest of these groups, the *mammals*, is divided into three subgroups, the *monotremes* or lowest, including but a few rare mammals found about Australia (Fig. 140), having a body and skeleton much like a mole or hedgehog; a flat bill and web feet like a duck or alligator; and which *hatch their young from an egg* like a bird or reptile. The next higher subgroup, the *marsupials* (Figs. 140, 145), includes a greater number of mammals, but, with the exception of the opossum of America, they are all found in Australia and the neighboring islands. These animals bring forth their young alive—that is, after the egg-envelope is broken—but the young are brought forth in such an imperfect condition that for some time after birth they are carried, attached to the breast of the mother, in a pouch, or fold, of skin with which she is provided. The highest of the three subgroups include all the rest of the mammals, from the *armadillos*, *ant-eaters*, and *sloths*, which have the lowest and simplest, to *man*, who has the highest and most complex, organization.

By comparing the characteristics of these great primary groups, one is immediately struck by the fact that in both the vegetable and animal kingdoms the organisms show a progressive but gradual complication of structure, and a corresponding specialization of function in their several parts or organs; from low, independent organisms without definite structure, consisting simply of minute masses of protoplasmic jelly, all parts of which possess equal ability to perform all the duties essential to continued life, they increase to forms of highly complex structure, possessing many distinct organs, each adapted to a special function.

Fig. 136. Mature amœba, and germ-cells of successively higher groups.

A progressive complication of structure similar to that exhibited by the great primary groups, occurs also during the very early, or *embryonic*, development of every individual in the higher groups of organisms. As already stated, every organism, even the highest and most complicated, is at first a simple germ-cell which often can not be distinguished from the mature single-celled organisms of the lowest groups (Fig. 136). The embryo, in acquiring the complicated structure peculiar to its own group, passes in succession through stages in which it closely resembles more nearly mature organisms of lower groups.

In Fig. 137 is shown a section of an embryo animal in each of the primary groups, at the *gastrula* stage. This stage occurs just before maturity in the sponge, but at successively younger periods in the higher groups. Fig. 138 shows successively younger embryos from successively higher groups of the vertebrata.

S. indicates stomach cavity.

Fig. 137.

Fig. 138.

The fossil remains of ancient forms of life indicate that in general the more complex and specialized organisms appeared on the earth at successively later dates in its history. The oldest rocks in which metamorphism has not so nearly obliterated the fossils as to render their original form quite unrecognizable, are those of the Cambrian period. In these rocks, fossil *thallogens* (sea-weeds) are found, but no forms of any higher vegetable groups. Fossil representatives of most of the lower animals are also found, but none of any higher group than *arthropoda*. It is not until late in the succeeding Silurian period that fossils of a higher group of plants and animals (*acrogens* and *vertebrates*—fishes) first appear. But fishes are the lowest group of the vertebrata. At successively later periods fossils of higher groups are found in the order of their complexity (*gymnosperm* plants and *amphibians* and *reptiles*), and at still later periods the still higher groups of

birds, mammals, and angiosperm plants, while the earliest remains of the highest organism, man, do not occur until a very much later period.

In the interval between the appearance of successive groups, fossil forms, now extinct, are occasionally found, that show a structure intermediate between the two groups. Thus, the fishes are linked to the amphibians, and the reptiles to the birds, by extinct fossil forms curiously blending the structures of both groups; while the lowest Australian mammal, with its peculiar web-footed structure and curious functions of laying eggs and yet suckling its young when hatched, is sometimes called a "living fossil," being really a link between the reptiles and the mammals.

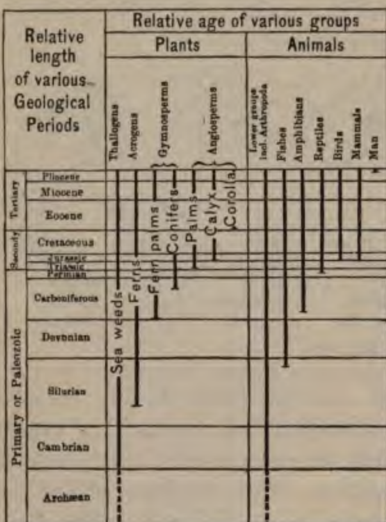


Fig. 139.

The Development Theory.—Three great facts are thus presented to us: (1) living organisms increase more or less gradually in complexity of structure, from the lowest to the highest; (2) there is a gradual complication of structure of each organism during its development, from a simple germ-cell resembling the lowest forms, through stages resembling successively higher forms; and (3) fossils of successively more complicated forms of life appear at successively later periods of time. A consideration of these facts has led to the belief that life first appeared upon the earth at an inconceivably remote period in the past, as a single kind or a very few kinds of organisms of the

simplest structure; and that as age succeeded age, different descendants of these organisms encountered different changes in their environment, and thus were differently altered in structure and function, each to conform to its peculiar surroundings, each generation undergoing, through its power of *adaptation*, a very slight change of form, and transmitting it to the next generation, through the power of *heredity*. As countless generations followed one another, the imperceptible changes in each gradually produced organisms differing widely in both structure and habit, or function, from their remote ancestors; and as the surroundings of different organic groups differed greatly, so did the resulting organisms differ from one another as widely as from their common ancestors. Thus, it is conceived, has arisen not only the infinite variety in the organic forms inhabiting the world, but the remarkable adaptation of each form to its special surroundings, or environment.

Great, though exceedingly gradual, changes of environment would naturally ensue (1) from the gradual transference of organisms into new localities, by winds, currents, other organisms, or their own powers of movement; (2) from gradual changes of climatic or other conditions resulting directly or indirectly from the cooling of the planet, the slow movements of the earth's crust, or the equally slow effects of erosion; and (3) from the sharp competition for food and other necessities (air, moisture, light, etc.), resulting from the continued multiplication of organisms in the same locality. It is probable that such competition has tended more than any other one cause to produce the endless variety and the progressive complexity of organic forms; for, where competition is sharpest, only those organisms that are most perfectly fitted, or adapted, to their surroundings get a sufficiency of the requisites of life, while the less perfectly adapted organisms have to migrate or perish. The favorable peculiarities of the survivors are inherited by their descendants, and in a few generations become common. Then individuals possessing some new peculiarity become the favored and successful form.

CHAPTER XXIII.

DISTRIBUTION OF LIFE.

I will plant in the wilderness the cedar, the acacia tree, and the myrtle, and the oil tree; I will set in the desert the fir tree, the pine, and the box tree together: that they may see, and know, and consider, and understand together, that the hand of the Lord hath done this.—ISAIAH XLI: 19, 20.

In general, the number of all forms of life decreases with the temperature and moisture of the climate. Thus, in the equatorial regions, where heat and moisture are great and continuous throughout the year, the luxuriance of both animal and vegetable life is astonishing. Dense, continuous, and evergreen forests are the striking feature of the vegetation. The trees not only stand very close together, but their trunks and branches are entwined with huge climbing vines, which, stretching from tree to tree, and interlacing with tall, tree-like ferns, grasses, and other plants, present an almost solid mass of vegetation often quite impassable by man. It forms a congenial home, however, for myriads of animal forms—mammals in great variety, birds of gorgeous plumage, reptiles of many kinds, toads and frogs, snails and other land shells, together with hosts of butterflies, moths, beetles, and other insects.

In passing from such regions to polar latitudes, one may observe that the forests gradually become more open, and the undergrowth less dense, while the animal forms become less numerous and less varied. As latitudes are reached in which the difference between winter and sum-

mer temperatures is more marked, the broad-leafed plants that were evergreen nearer the equator become *deciduous*, that is, they lose their leaves on the approach of winter; while almost the only remaining evergreens have needle leaves, like the pines, or plate-like foliage, like the cedars. This change in vegetation is accompanied by a corresponding change in the form and habits of animals. With the seasonal stoppage of plant growth, many of the animals are forced to migrate into warmer latitudes in search of food; others are adapted to pass the winter in a nearly unconscious state in some secure retreat, underground, in hollow trees, or elsewhere; while many take on a thicker covering of hair, fur, or feathers at the approach of winter.

In still higher latitudes, even such hardy trees as pines, firs, larches, and spruces can not withstand the cold winters; all trees and even tall shrubs disappear, and in the polar lands only such low plants can mature their seeds during the short growing season as can be safely covered by the snow during the long winter, such as mosses, lichens, and strangely dwarfed and stunted shrubs. The animals of these cold latitudes are comparatively few, and, like the plants, are specially adapted to withstand the severe climate.

The low northern margins of both America and Euro-Asia lie partly in this cold region, and the ground is frozen to a great depth. Only a thin layer is thawed during the short summer. The water from the melting snow, unable to penetrate the frozen ground beneath, converts the flat region into a great morass, or *tundra*, in whose shallow soil the mosses, lichens, and other low forms of vegetation peculiar to the region find sufficient foothold.

Variation with Altitude.—A very similar series of changes in the organic world may be observed in ascending a very lofty mountain range in the torrid zone. As the temperature falls with the ascent, the rank vegetation

and exuberant life of the lowlands are replaced by organic forms, which remind one of those to be found in the lowlands of colder latitudes. Finally, an altitude is reached where tall tree-growth ceases, and is succeeded by a region in which the vegetation consists only of mosses, lichens, and stunted shrubs. As the vicinity of the snow line is reached even these fail, and all forms of life are left below.

Effects of Moisture — Forests.—But the organic forms do not depend upon temperature alone. Forests, with their peculiar forms of animals, occur only where the rain-fall is abundant throughout the growing season. In regions where the rain-fall is but moderate, or very unequal at different seasons, the forests are replaced by the low vegetation peculiar to open meadows, or pastures.

Open Meadows.—Plains having this form of vegetation are called prairies, steppes, llanos, pampas, and campos in different regions. With the change of vegetable forms from forests to meadows, a corresponding change takes place in the animal forms. Those common in the forest are rarely seen, but are replaced by other forms better suited to the open country and the altered conditions of climate.

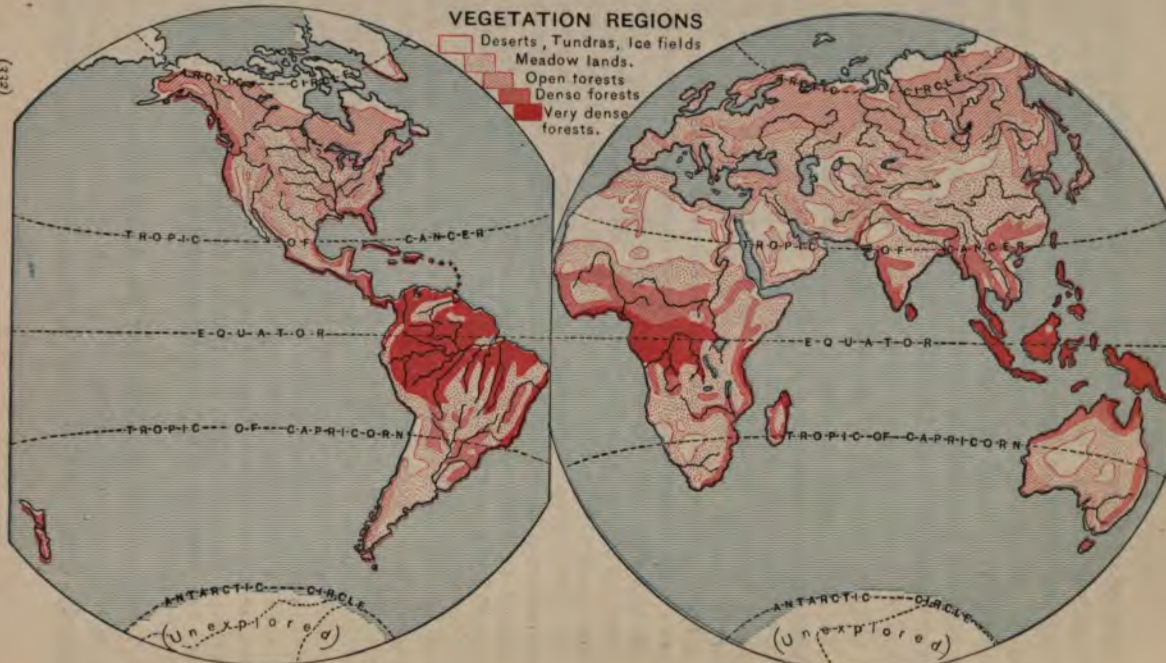
The meadow vegetation may be evergreen in low latitudes, where the annual temperature is uniform, if the rain-fall is equally distributed through the year; but where precipitation is very intermittent, the vegetation is burned crisp and brown, and killed to the roots by the great heat in the dry season. Thus, in the llanos of Venezuela, in the warm valleys of California, in parts of India, and in many other regions, the surface is covered with verdure during the wet season, but assumes the parched aspect of a desert during the dry season.

Deserts.—In still other regions, where the rain-fall is very slight, vegetation of any kind is scanty or entirely wanting, and a true desert is the result. The animal

forms of deserts must manifestly be very different from those of forests or meadow lands, not only because of the scarcity of water to drink, but because of the dearth of vegetable matter which, directly or indirectly, affords food to all animals. Hence, desert animals must be adapted not only to traverse great distances in order to collect enough food from the scanty vegetation, but also adapted to escape, by flight, or strength, or concealment, from other animals which subsist on animal food.

The close relation between the rain-fall and the character of vegetation, may be appreciated by comparing the chart of Vegetation Regions (page 332), with that of the Rain-fall (page 76). It is seen that all deserts correspond to regions of very light rain-fall, and that the regions of heaviest forests are in regions of heaviest rain-fall. But it is also seen that the northern regions of open forests in both America and Euro-Asia lie mostly in regions of moderate rain-fall; while in both South America and Africa, certain regions of heavy rain-fall have only meadow-land vegetation. These apparent anomalies are the result of inequalities in the annual distribution of rain-fall. In low latitudes, the high, uniform temperature permits plant growth during the entire year; but where wet and dry seasons alternate, the plants are killed to the roots during the dry season, and only the low herb or shrub vegetation of meadows can mature during the wet season. In high latitudes, however, the great annual variation of temperature adapts some plants to pass a great part of the year (winter) in a dormant condition, and to begin growth in the spring where they left off growing in the autumn. In such latitudes, if a small annual rain-fall occurs mostly during the short growing season, it produces the same effect upon vegetation as a larger annual rain-fall in latitudes where the growing season is longer. To a certain altitude, mountain ranges generally receive a heavier rain-fall than the adjacent lowlands, and for this reason are usually forest-clad, though they rise from the midst of extensive treeless plains, or even from deserts (page 311).

Distribution of Different Kinds of Life.—While the general form and habit of plants and animals are thus largely determined by the climate, there are many pe-


VEGETATION REGIONS
Deserts, Tundras, Ice fields
Meadow lands.
Open forests
Dense forests
Very dense forests.
ARCTIC CIRCLE
TROPIC OF CANCER
EQUATOR
TROPIC OF CAPRICORN
ANTARCTIC CIRCLE
(Unexplored)

culiarities which climate alone will not account for, when the *kinds* of plants or of animals in one region are compared with those in another. If climate were the sole cause of the present distribution of plants and animals, we should expect to find the organisms of different regions having very similar climates more closely related to each other than those living in regions having very dissimilar climates. But very frequently this is not the case.

Many of the organisms of semi-tropical Florida and Georgia have nearer relatives in the Arctic regions of both America and Euro-Asia, than in the closely neighboring Bahama Islands, Cuba, or Yucatan, where the climate is so much more nearly the same. Parts of equatorial South America and west Africa are almost identical in climate, and yet differ widely in their assemblages of plants (flora), and of animals (fauna). The flora and fauna of Euro-Asia north of the Himalaya Mountain system differs less from that of North America than it does from either that of Africa south of the Sahara, or of Asia south of the Himalaya range. These latter regions, though often similar in climate, differ greatly from each other in flora and fauna, while many of the plants and most of the animals of Australia, which closely resembles parts of south Africa in climate, have no near relatives in that continent.

In general, every region of the land that is broadly separated from surrounding regions by great differences of climate, or strongly marked physical barriers to the passage of plants and animals, such as the sea, lofty mountain chains, or wide areas of desert, differs to a greater or less extent from the surrounding regions in flora and fauna. The amount of this difference is roughly proportional (1) to the completeness of the separation, or *isolation*, of the regions, and (2) to the length of time they have been separated;—the difference being greatest where the isolation is greatest, and has endured for the longest time.

The development theory explains why this should be the case. The environments of organisms in two regions are never exactly the same, and each environment is constantly, though perhaps very


BIOLOGICAL REGIONS
AUSTRALIAN
PAPUAN
ORIENTAL
CHINESE
EURO-ASIAN
MEDITERRANEAN
AFRICAN
NORTH AMERICAN
MEXICAN
SOUTH AMERICAN
PACIFIC OCEAN
ATLANTIC OCEAN
INDIAN OCEAN
NORTH POLE
EQUATOR
Drawn on the same projection as the map of Regions of Elevation & Depression.
The Continental Plateau is enclosed by the darker blue shading.
South American Region.
North American Region.
Euro-Asian Region.
African Region.
Oriental Region.
Australian Region.
Transitional regions.

slowly, changing, while the organisms and their descendants in each region are constantly and gradually changing also—each organism adapting itself to its own special environment. Hence, if very similar and closely related organisms were placed in two regions separated from each other by impassable barriers, their remote descendants would inevitably be very different, not only from their similar ancestors, but from *each other;* whereas, if no barriers existed, the descendants in either region would constantly mingle with those in the other region, and the related organisms would thus tend to continue similar in the two regions, though in both they might eventually develop features which their ancestors did not possess.

Primary Biological Regions.—A comparison of the floras and the faunas of different lands indicates that the continental plateau may be divided into six great biological or life regions, each characterized by the abundance of certain kinds of plants and animals belonging to great organic groups that are not represented at all, or not nearly so abundantly, in any other region. Each geographical grand division, with one exception, corresponds roughly with a single primary biological region. Thus, we have (1) the South American region; (2) the North American region; (3) the Euro-Asian region; (4) the African region; (5) the Australian region; and (6) the Oriental region, which comprises the greater part of the Malay Archipelago and the portion of the main-land of Asia south and east of the Himalaya Mountains.

Where the primary regions are not separated by the great óceanic depressions, their boundaries generally overlap each other, producing *transitional regions,* in which the characteristic plants and animals of both the adjacent primary regions are found to a greater or less extent. There are at least four transitional regions: (1) the Mexican region, embracing Mexico and the hot desert region of the south-west United States; (2) the Mediterranean region, embracing both coasts of that sea and the continuous desert territory on the south and east, from the Atlantic to the valley of the Indus and the Hindoo Koosh Mountains; (3) the Chinese region from the Nan Ling (mountains) on the south, to the Khin Gan system

on the north; and (4) the Papuan region, embracing Celebes, Papua, or New Guinea, and the smaller neighboring islands of the Malay Archipelago. On the chart (page 334) the approximate boundaries and the relative positions of the primary and transitional regions of the continental plateau are indicated. It will be observed that these transitional regions occupy territory in which there is a marked transition in climate, or well marked peculiarities of surface, such as high mountain ranges, broad deserts, or wide areas of the sea, which constitute a succession of barriers to the free passage of organic forms between the adjacent primary regions.

A seventh biological region may be said to embrace all the oceanic island groups, for although the various groups differ from one another in flora and fauna, still they all possess in common certain striking peculiarities when compared with the continental regions, and these peculiarities throw some light on the general distribution of life.

Characteristics of the Island Region.—Of all regions, that of the oceanic islands is most completely isolated, both as to space and time. Each island group is not only separated from the continents by a great width of ocean, but all evidence indicates that it has always been so separated. Hence, we should expect that each island group would be peopled with species of plants and animals found nowhere else in the world, and this, *in general*, is the case. Though peculiar in species, the island organisms almost always show a greater or less resemblance in internal structure to, and are hence the near or remote kindred of, organisms inhabiting the nearest continent—though this may be hundreds of miles distant— and this resemblance is greatest in islands where strong prevailing winds and oceanic currents move directly from the continents toward the islands. The bearing of these facts becomes apparent, when, upon closer examination, it is found that all the native plants and animals of oceanic islands are of kinds

which, at some stage of life, are specially adapted for a wide dispersal, either through the agency of winds or of ocean currents. These facts, in connection with the absence of fossil remains of very ancient forms of life, render it nearly certain that the oceanic islands are peopled by such stray forms of continental plants and animals as find a congenial environment after being cast upon their shores by the direct or indirect agency of the winds and oceanic currents; and that the amount of peculiarity in any special form of island life is proportional to the length of time since the arrival of its first island ancestors or any similar forms.

Among the most common plant groups of oceanic islands are the ferns, grasses, and sedges; some of the palms; the group including the thistle and dandelion; and that to which beans, peas, and the locust belong. The seeds of all these plants are lighter than water; they retain vitality long after detachment from the parent stem; and either (1) are very minute and furnished with a wing-like "down," which adapts them for transportation by the winds; or (2) are enveloped in a water-proof shell, or pod, which enables them to float safely; or (3) in a bur, which will adhere to the plumage of birds; or (4) are so protected in a small fruit or berry, which birds swallow whole, that the living seed-germ may be transported in the bird's stomach over great distances. There are other groups of plants represented on oceanic islands, but seldom or never any having heavy or perishable seeds. The native animal groups seem to be exclusively confined to birds, insects, bats, certain land mollusks, and certain reptiles. The first three can fly. Mollusks are very tenacious of life; some can seal their shells up water-tight, and thus float safely for many weeks; others reach islands attached to floating driftwood; while the living eggs of still others have been found in the mud attached to the feet of birds. The eggs of island reptiles, generally lizards, are doubtless thus transported, attached to the feet of birds or bats. The absence from oceanic islands of all native four-footed mammals, all amphibians (toads, frogs, etc.), and all fresh-water fishes, renders the fauna strikingly peculiar. The influence of the direction of winds and currents upon the amount of peculiarity of island life is well shown by comparing the life-forms of the

Bermudas, Azores, and Galapagos islands respectively, with those of the nearest continental region, from which they evidently were originally peopled. The constant Gulf Stream and regular winter west winds so frequently carry American forms of life to the Bermudas, that the island breeds are kept similar to the continental breeds, and few distinct species are found. The regular winds and currents move *from* the Azores *toward* Europe, and stray life-forms from Europe are brought to the islands only occasionally by the intermittent cyclonic or storm winds, and hence time is allowed for many species to become peculiar. The Galapagos Islands are nearer to a continent than either of the other groups, but lie in the calm, stormless, equatorial region of the Pacific, and immigrants arrive so seldom that *all* the organisms belong to distinct local species, excepting the extensive migrator, the rice-bird, or bobolink.

No one of the continental regions is so completely isolated from all others as the island region, and between none of them are the present barriers nearly as permanent as the great sea-barrier which isolates the oceanic islands; for, as a result of the constant but gradual upheaval or depression of portions of the continental plateau, the continents and grand divisions have been both more closely united, and more effectually separated, than they are at present. Climatic barriers have also changed materially on the continental plateau, for such alterations of level, through their effect upon the direction of oceanic and atmospheric currents, have been largely instrumental in bringing about such vast changes of climate in the past as are evidenced by the occurrence in arctic lands of the fossils of tropical plants and animals; and by the traces of continental glaciers, which indicate the existence of an arctic climate as far south in the United States as the Ohio valley. It has thus been possible in the past for representatives of all the *great* groups of plants and animals to migrate to and fro between continental regions that are now separated by impassable climatic or physical barriers. Hence, these regions differ among

themselves in organic forms much less than they collectively do from the island region, and the difficulty of accounting for the existing differences and resemblances of flora and fauna is vastly increased, and frequently rendered quite impossible.

The Australian region is by far the most peculiar of the continental regions, since, in addition to a great number of peculiar kinds of plants, its mammals, with scarcely an exception, belong to two small and very peculiar subgroups (Fig. 140),—the monotremes, or egg-layers, which are found in no other region, and the marsupials, or

Duck-Mole. *Kangaroo.* *Brush-turkey. Emu.*

Fig. 140.—Characteristic Animals of Australia.

pouched animals. These, though represented by the kangaroo and many variously adapted forms in Australia, are not represented by living varieties in any other region excepting the two most distant from Australia:—a few kinds of this subgroup (about twenty varieties of opossum) being found in South America, and two varieties occurring in the United States.

Among the more characteristic and peculiar plants of Australia are the leafless beef-wood trees, the very numerous and generally leafless varieties of the acacia; the great eucalyptus trees, whose leaves grow with their edges to the sky, so that they cast but little shade; the heather-like epacris; and (especially in New Zealand) many filmy- and tree-ferns. The characteristic plants are most numerous in southern Australia, while in the north they are mixed

with palms and other tropical plants, identical or nearly so with the plants of the Malay Archipelago and south-eastern Asia, from which region they have doubtless reached Australia, in comparatively recent times. The peculiar birds of Australia include piping crows, honey-suckers, lyre-birds, cockatoos, gayly colored pigeons, brush-turkeys or mound-builders, and the almost wingless emus and cassowaries, whose nearest relatives are the ostriches of Africa and the rheas of South America.

Sloth. Rhea. Prehensile-tailed Monkey. *Armadillo. Curassow. Llama.* *Ant-eater. Condor. Jaguar.*

Fig. 141.—Characteristic Animals of South America.

The South American region, though its flora and fauna are among the richest and most varied in the world, probably ranks after the Australian as the most peculiar region. The striking characteristic of this region is the preponderance in its fauna of lowly organized types (Fig.

141). The marsupials (opossums), edentates (sloths, armadillos, and ant-eaters), and such rodents as the cavys, guinea-pigs, and agoutis, form the majority of the mammals, while the more highly organized carnivora and hoofed-animals are not only exceedingly deficient, but are smaller than their kindred in the old world; the tiger, lion, rhinoceros, camel, and hog of the old world, being represented by the respectively smaller jaguar, puma, tapir, llama, and peccary in South America. The same relatively low type of organization characterizes the South American monkeys and birds. The nostrils of the former face outward instead of downward, and most of them are prehensile-tailed; and an unusually large proportion of the birds are songless; while the tinamous and rhea, and the curassow, are allied respectively to the lowly organized ostriches, and to the brush-turkeys of Australia.

Among the hundreds of peculiar plants of the South American region may be mentioned the mahogany, rose-wood, and logwood, the cinchona or Peruvian bark tree, and plants yielding India rubber, many spices, balsams, and varnishes, a great variety of laurels, bean-trees, and palms, many cacti and orchids or air-plants (one of the latter yielding the vanilla bean), peculiar varieties of bananas, tree-grasses (bamboo), and tree-ferns, and the peculiar varieties of the nightshade family, such as Cayenne pepper, the potato, and tobacco, while Indian corn and the tomato are probably descendants of plants native in this region.

The African and Oriental regions possess marked peculiarities by which each may be distinguished from all the other regions; but the flora and fauna are more complicated, highly organized forms of life are more numerous, and the difficulty of accounting for the present distribution is vastly greater than in the two preceding regions. The African region is the more peculiar. It differs markedly from South America and Australia in the great development of the highly organized carnivora

Aard-vark. Giraffe. Lion. *Pangolin. Gnu. Hippopotamus.* *Ostrich. Zebra. Gorilla.*

Fig. 142.—Characteristic Animals of Africa.

and hoofed-animals, especially antelopes, of which more kinds (80 or 90) are found than in any other region. Besides these, the hippopotamus, giraffe, zebra, quagga, and wild ass (the ancestor of the domestic animal) are found nowhere else. Such widely spread animals, however, as bears, moles, deer, sheep, and goats are completely absent from the African region. With these marked differences, this region more than any other resembles South America in possessing a moderate number of the lowly organized edentate animals (the ant-eating aard-varks and pangolins). The carnivorous animals include the lion, leopard, panther, several kinds of hyenas, the jackal, aard wolf, and

Fig. 143.—Characteristic Animals of the Oriental Region.

a great variety of civet cats. Most of these, as well as near relatives of the African elephant and rhinoceros, are also found in south-eastern Asia, and are characteristic of the Oriental, rather than of the African, region. The monkey tribe of the two regions embraces the man-like apes—the gorilla and chimpanzee of Africa, and the orang-outang of Farther India,—besides numerous baboons, true monkeys, and the peculiar half monkeys, or lemurs. Among the peculiar African birds may be mentioned the true ostrich, the serpent-eating secretary-bird, many guinea-fowls, vulture-crows, plaintain-eaters, crested tourocos, and colies.

The Oriental region is characterized by its orang-outangs, and by a greater development of carnivorous

animals than Africa; for, in addition to the lion, leopard, hyena, etc., it possesses the tiger and ounce. It differs from Africa, too, in having bears, several kinds of deer (muntjac, chevrotain, etc.), wild cattle (the gayal and others), wild hogs, and a tapir closely related to the South American animal. This region is the head-quarters of true mice and squirrels, and contains some very peculiar flying lemurs. Among its characteristic birds are babbling-thrushes, hill-tits, green bulbuls, numerous crows and hornbills, and a great variety of magnificent pheasants, including the peacock and jungle-fowl, from which the domestic chickens are descended.

The African flora embraces the oil-palm, the great baobab, euphorbias, bignonias, and tamarinds, together with many varieties of laurel, fig, myrtle, acacia, and mimosa in the dense forest region of the west. On the more open eastern tablelands, tall grasses, sedges, and the coffee tree are characteristic plants; while the remarkably rich flora of the south includes a great variety of heather, fig-marigolds, and aloes, together with some close allies of characteristic Australian and South American plants. The flora of the Oriental region as a whole has fewer distinctive features than that of Africa or South America. The region is relatively small, and has a great climatic range, from the perpetual snows of the Himalayas to the equatorial lowlands of Java, and hence many plants from adjacent regions can reach congenial environments within its boundaries. Along the Himalayas many pines, junipers, yews, cedars, and some oaks occur. In the dry districts of north-west India many acacias and the tamarisk are found. In the moist forest regions of the south and south-east, pitcher-plants, wood-oil trees, custard-apples, mangoes, numerous palms, cycads, and many spice-yielding plants abound, while teak, toon, sal, ebony, satin-wood, sandal-wood, and iron-wood are characteristic timber trees.

The Euro-Asian and North American regions, though more extensive, differ from each other less in flora and fauna than any other two regions. By some they are classed as a single region, but minor differences seem to warrant their division. The more common and conspicu-

ous animals, such as the various wild cats, lynxes, wolves, foxes, weasels, bears, elk, deer, voles, beavers, squirrels, marmots, and hares, are identical, or very similar, in the two regions. Even the grizzly bear of the Rocky Mountains and the buffalo (bison) of the Great Plains are thought to be but slight variations of the European brown bear and the nearly extinct aurochs of west Russia. But with these there are in each region numerous less conspicuous animals not found in the other, and some found nowhere else; thus, the star-nosed mole, skunk, raccoon,

Chamois. Hedgehog. *Ibex. Camel.* *Wild Boar. Desman.*

Fig. 144.—Characteristic Animals of Euro-Asia.

puma or panther, prong-horned antelope, Rocky Mountain goat, big horn sheep, musk-ox, musk-rat, jumping-mouse, prairie-dog, gopher, tree-porcupine, sewellel, otter, and opossum occur in North America but not in Euro-Asia, while hedgehogs, wild boars, dormice, badgers, camels, yaks, saiga antelopes, and nineteen kinds of wild sheep and goats occur in Euro-Asia but not in America.

The same general resemblance with numerous special differences characterizes the birds and plants of the two regions. Eagles, owls,

Big Horn. *Prairie-dog.* *Prong-horned Antelope.* *Opossum.* *Gopher.* *Buzzard*

Fig. 145.—Characteristic Animals of North America.

hawks, crows, thrushes, wrens, tits, and finches occur in both, but America alone possesses humming-birds, wild turkeys, turkey-buzzards, blue jays, tanagers, hang-nests, and mocking-birds; while Euro-Asia is peculiar in its starlings, magpies, nightingales, true fly-catchers, partridges, pheasants, vultures, etc. Among plants, both regions exceed all others in the development of the pine family, including the pines, larches, spruces, firs, hemlocks, cedars, etc.; and of the oak family, including oaks, chestnuts, beeches, hornbeams, etc. The ash, elm, sycamore, walnut, and maple are also characteristic plants, as are also numerous gentians, rushes, primroses, birches, willows, and saxifrages. The American region is peculiar in its asters, golden-rod, sequoias, and bald cypresses, while Euro-Asia shows the greater development of heather, roses, olives, almonds, etc.

Taken as a whole, the more highly organized forms of life preponderate on the land masses of the northern hemisphere—North America and Euro-Asia,—the great central region of the continental plateau (see chart, pages 152, 153); while forms of land life of lower organization are characteristic of the extremities of the continental

plateau which project into the southern hemisphere—South America, south Africa, and Australia. Now, when all the fossils of ancient organisms from different parts of the world are compared, it is found that the collection from the three northern regions includes not only the evident ancestors of the forms now occupying those regions, and of the more highly organized forms now confined to the southern hemisphere, but from the older rocks come the fossil ancestors of the lowly organized forms now characteristic of the southern land masses.

Not only do the fossils prove that the elephant, rhinoceros, and hippopotamus were once far more abundant in Europe than they are now in the tropics, but they also prove that the man-like apes of west Africa and Malaya, the lemurs of Madagascar, the edentata of South America and Africa, and the marsupials of Australia and South America were all inhabitants of Euro-Asia and North America at the beginning of the tertiary era of geological time. Though animal forms are preserved as fossils much more frequently than vegetable, still the indications are that the same facts are as true of plants as of animals.

These facts indicate that at least during the vast length of time that has elapsed since the beginning of the tertiary era, and probably for much longer, the great land masses of the northern hemisphere have occupied substantially their present sites, and that in this great compact central region of the continental plateau, as it underwent the long series of changes which resulted in its present physical conditions, all the successive types of land organisms gradually developed, from the lowest to the highest.

In the southern hemisphere, there appear to have been three smaller but equally ancient land masses, varying gradually in extent, but always keeping distinct from each other, and occupying roughly the sites of Australia, South America, and south Africa, respectively. From time to time gradual movements of the earth's crust tempo-

rarily united these isolated extremities of the continental plateau with the great central land mass, and during each connection, which may have lasted thousands of years, the various forms of life then prevalent in the central continents gradually found their way southward. After a longer or shorter union, the gradual subsidence and submergence of the connecting land stopped this migration, and a period of isolation began.

During these periods of isolation, the organisms in the central region developed much more rapidly than their respective kindred in the detached region, not only because the central region underwent more frequent changes of environment, through movements of the earth's crust, erosion, etc., within its more extensive area, but because it contained a greater variety of environments, and hence developed a greater variety and a greater number of organisms. Therefore, competition for food and other means of existence was very sharp in the central region; each organism was compelled to *use* all its faculties to secure a livelihood, and all but the more perfectly adapted organisms perished. Thus the more lowly organized forms of life gradually became extinct, and were successively replaced by their more highly organized descendants. In the relatively small isolated regions, however, the number of organisms was relatively small, and the competition for food was not sharp; and in consequence the descendants of the lowly organized immigrants, though changing slightly, developed toward a higher organization with extreme slowness. Thus, upon the reunion of an isolated region with the central land, the migrants from the latter were much more highly organized than the inhabitants of the newly attached region; and if the immigrants were numerous, they gradually exterminated and replaced their competitors of lower organization.

Australia appears to have had but one such union with the central region, and that at a very early period, when monotremes and marsupials were the predominant forms of mammalian life. South Africa and South America each appear to have had a succession of such unions and separations, allowing the immigration first, of low forms only (edentates, lemurs, etc.); subsequently, of rodents and small carnivora; and lastly, of the higher forms of apes, carnivora, and hoofed-animals. It appears that North America and Euro-Asia have frequently and for long periods been more closely united in the arctic regions than they are to-day, and at times when a moderate polar climate permitted an easy interchange of organic forms; yet there probably was a time in the remote past when the arctic separation was more complete than at present, and when North America was a relatively small, isolated region of the great continent of Euro-Asia, which is thus probably the remote source from which all other regions were supplied with their higher forms of life. At that time, it is probable the Oriental and Euro-Asian regions were one—their final separation dating from the great upheaval of the Himalaya Mountain system.

Of the distribution of marine life, and the laws which govern it, but very little is known. The sea being continuous, and the water below a comparatively slight depth having an almost uniform temperature, it is not surprising that life-forms in various regions of the sea do not differ so greatly as in the various regions of the land. Nevertheless there are differences, the reasons for which are still in the highest degree problematical; thus, the king crab is found only on the widely separated coasts of Nova Scotia, Japan, and the Malay Archipelago. Marine vegetable life, with the possible exception of microscopic diatoms, seems to be confined to a depth of less than 100 fathoms, which is about the depth to which the luminous rays of the sun can penetrate the water. Marine animal life, however, though more abundant near the surface, exists near the bottom of all parts of the oceans, where, possibly on account of the greater food supply, it is thought to be more abundant than at intermediate depths.

[illegible]

[illegible]

[illegible]

Man. — [illegible] the [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] particulars [illegible] their [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] observation. [illegible] taken, [illegible] [illegible] [illegible] [illegible] same materials and [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] which [illegible] [illegible] [illegible] [illegible] [illegible]

The fundamental resemblance [illegible] animals [illegible] [illegible] [illegible] [illegible] [illegible] and they [illegible] [illegible] [illegible] [illegible] resembles the [illegible] [illegible] [illegible] [illegible] others.

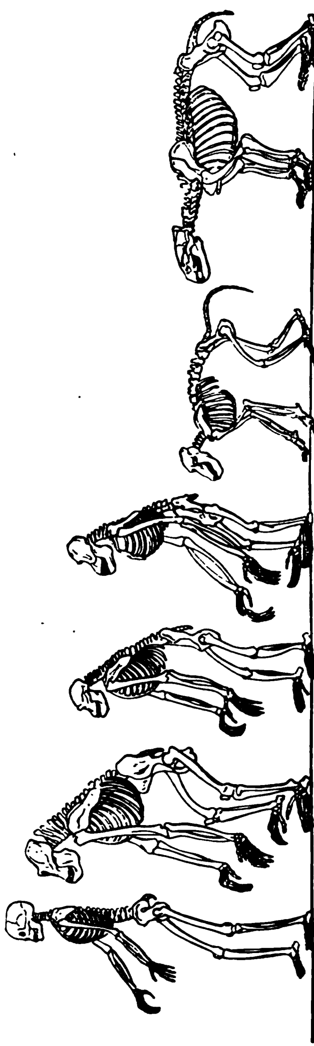


Fig. 146.—Skeletons of Man, Monkeys, and Quadruped.

since he and they possess an internal bony skeleton, built upon a jointed backbone, containing a spinal nerve-cord, which leads from a principal nerve-center, or brain, in the head. Still closer is his likeness to the mammals, which, like man, nourish their young from the breast.

While possessing a close structural resemblance to all mammals, man resembles some kinds much more closely than others, as indicated in Fig. 146. The resemblance between man and the man-like apes is indeed much closer than may be appreciated from this sketch, for even such details of structure as determine the difference between the hand and the foot of man are found to be also well marked in the higher members of the monkey tribe, which therefore possess true hands and feet. In fact, the extremities of the man-like apes differ in structure less from those of men than from those of the lowest monkeys, or *marmosets* (Fig. 147).

Man differs most widely from all the lower animals in his vastly greater mental capabilities. The organ of the mind—the brain—is,

Fig. 147.—Hand and Foot of Man and Monkeys.

on the average, about three times as large in man as in those animals which resemble him most closely in structure;—the average man having about 87 cubic inches of brain, while the gorilla, an animal about twice as heavy as man, has less than 30 cubic inches. In addition to this, the surface of man's brain is furrowed by a vastly more complicated system of fissures, or *sulci*, and intervening folds, or *convolutions*. The surface area of man's brain is thus greatly enlarged, and mental power is supposed to depend to a great extent upon the surface area of the brain (Fig. 148).

Though the brain is larger and mental power immeasurably greater in man than in the higher beasts, the difference in the *structure* of the brain is relatively slight. Prof. Huxley, one of the greatest anatomists of the present age, has carefully compared the brain of man with that of various members of the monkey tribe, and has found that "so far as cerebral (brain) structure goes, man differs less from the chimpanzee or orang-outang than these do from

the (lower) monkeys," while "the (structural) difference between the brains of the chimpanzee and of man is almost insignificant, when compared with that between the chimpanzee brain and that of the lemur (the peculiar half-monkey of Madagascar). The argument," Huxley continues, "that because there is an immense difference between a man's intelligence and an ape's, therefore there must be an equally immense difference between their brains, appears to me about as well based as the reasoning by which one would endeavor to prove, that because there is a 'great gulf' between a watch that keeps accurate time and another that will not go at all, there is therefore a great structural hiatus (difference) between the

Fig. 148.—Brain of Man and Monkeys.

two watches. A hair in the balance wheel, a little rust on a pinion, a bend in a tooth of the escapement, a something so slight that only the practiced eye of the watchmaker can discover it, may be the source of all the difference. And believing, as I do (with Cuvier), that the possession of articulate speech is the grand distinctive character of man, I find it easy to comprehend that some equally inconspicuous structural difference may have been the primary cause of the immeasurable and practically infinite divergence of the human from the ape (family)."

The fact that, physically considered, man resembles the higher beasts as closely as these resemble the lower

animals, in connection with the fact, now generally admitted, that the higher and lower animals are but differently modified descendants of a common kind of ancestors, leads to the *inference*, that man himself is a still differently modified descendant of the same remote ancestors. The difference in the degree of mental power, however, between civilized man and even the highest beast, is apparently so much greater than that between the highest and even the very lowest animal, that it is hard to conceive of any natural process, by which such an almost infinite divergence could have taken place in organisms descended, however remotely, from similar ancestors.

Whatever may have been the origin of man, and whatever may be his true relationship to the higher animals which he resembles so closely in structure, we know that he has been an inhabitant of the earth for a time very much greater than the 4,000 or 5,000 years of which history or tradition preserves a record. This is known from the occurrence of fossils of man—human bones, and implements made by man—associated in deposits with the fossils of extinct animals of the late tertiary or early quaternary era. This, though quite recent when compared with the lapse of geological time, indicates that man, as a tool- or implement-making animal, inhabited the earth tens, or possibly hundreds, of thousands of years ago, while relics of man, found in deposits of intermediate ages, indicate that he has inhabited the earth *continuously* during this long but indefinite period.

We know that man has changed but little in his structure and manner of thought during the period covered by history and tradition, but that his general knowledge and intelligence have increased greatly during this time. Although, at the dawn of history or tradition, man in ancient Egypt dwelt under an organized govern-

ment, knew the use of the more useful metals, practiced the art of agriculture, had sufficient knowledge of mechanics to build monuments which have endured until the present, and was thus vastly more civilized than many savage tribes are to-day; still, with all these attainments, his civilization was very greatly inferior to that of the present time. In following the history of mankind from that day to this, one may note the more or less gradual increase of knowledge, its broader diffusion among the masses, and the consequent slow, but on the whole continuous, progress in general intelligence and civilization.

The same kind of progress in the intelligence of prehistoric man may be dimly traced, by comparing his implements and other indications of his work and habits, as they are occasionally found in deposits of successively older date. As the age of the deposit increases, the implements become less various in shape, and simpler and ruder in construction; while the associated remains, when they afford any indication of the manner of life of prehistoric man, indicate that this was simpler and ruder in proportion as the deposit is older.

Thus, in going backward from the beginning of historic times in various parts of Europe, we find that the more modern prehistoric races of portions of that region made implements of iron and bronze, as well as of stone; had domesticated such animals as the ox, dog, sheep, and goat; lived together in settlements, and cultivated wheat, and the same kind of barley found wrapped with old Egyptian mummies. In earlier deposits, only implements of bronze and stone are found, while the associated bones of the dog, horse, and ox, and other remains indicate a pastoral rather than an agricultural life. From still older deposits come only implements of stone or bone, while the dog seems to be the only domestic animal. These stone implements, however, are neatly and symmetrically shaped, and have generally been ground down to a smooth and often polished surface, indicating a degree of intelligence in the makers decidedly greater than that found in the rudest savages. The oldest of all

implements of prehistoric man are those found associated with [illegible] now extinct. These earliest implements are [illegible] ... [illegible] ... made than the later ones, being simply flakes of flint, or later hard stone, roughly chipped into [illegible] shapes ... [illegible] ... point. Such implements are [illegible] made and used by the lowest and most ignorant tribes of savages, but are found in more or less recently [illegible] deposits in all parts of the world, as the most ancient [illegible] of man.

Such facts as these are held to indicate that all men—the most civilized races as well as the lowest—have descended from more or less remote ancestors who were as ignorant, and as low in the scale of intelligence and civilization, as the lowest savages of whom we have any knowledge. During the vast period of time which has elapsed since all mankind was at this low stage, different portions of the human family have developed their [illegible] powers in different lines, resulting in the various degrees of intelligence and civilization found among the people now inhabiting different regions of the globe.

[illegible] ... that though the indications of this progressive development of the human intelligence are so strong and numerous as to render the fact practically certain, still the most ancient [illegible] ... being no less distinctly human than are the lowest savages of Borneo and Terra del Fuego to-day. [illegible] ... intelligence of a [illegible] savage of the [illegible] ... Spencer, [illegible] Gladstone, or [illegible] ... accumulating evidence that the [illegible] has developed by gradual modification from the former [illegible] ... intelligence of the savage may [illegible] ... process, during the long ages of the [illegible] past ... was similar to [illegible] ...

Certain superficial differences [illegible] physical features are [illegible] ... methods have [illegible] ... separate [illegible] ... these differences are superficial, [illegible] ... When

the deeper seated and more essential structural features are compared, they are found to be so wonderfully similar in men from every region, as to warrant the belief that all mankind is descended from a single race.

An Englishman can generally be distinguished from a Dutchman by indefinable peculiarities of physical feature; but it is well known that the ancestors of these peoples formed a single race, and lived together in the region between Denmark and Belgium. About the year 500, a portion of this people went over and conquered Britain, where they settled and continued to dwell. These emigrants did not differ materially in feature from their former neighbors who remained at home, but their descendants were in great part isolated from their kindred on the main-land, and each portion, by adaptation to its special environment, gradually developed the peculiar features which characterize either people to-day. The fact that the slight but plainly perceptible race differences between the English and the Dutch have thus developed during 1,400 years of imperfect isolation of the two peoples, in two regions so closely adjacent as to have nearly the same climate and general surroundings, is held to afford conclusive evidence that the greatest differences between the most divergent races of men, may be accounted for by the operation of the same processes, during the vastly longer period of man's occupancy of the earth, and on descendants of an originally similar people, who became completely isolated from each other, in regions so widely separated as to differ markedly in climate and other conditions of environment.

Resemblances in language and customs are often found in races which now occupy widely separated regions and differ markedly from each other in physical feature. While such resemblances can not be found between all languages, they are thought, when they do occur, to afford direct evidence that these particular languages are but more or less divergent variations from a single primitive tongue, and that the races using them are descendants of the single race that used the primitive language.

Indeed, language is thought to afford the best available means for tracing the connection between various races. If the resemblance

is strong, involving whole sentences or very many words, the people are supposed to have been separated for a relatively short time. If the resemblance is only in an occasional word, the separation of the languages and the people using them, from the parent stock, is thought to be of very ancient date. If no resemblance at all can be traced between languages, the separation of the people using them from a common ancestral race is thought to have occurred at an exceedingly remote period, possibly before the race had acquired a common language.

The inevitable tendency in any people to change, which accompanies broad distribution and the consequent variety in environment, implies that the race from which the whole human family is thought to have descended, originally occupied a region of rather limited extent, and that the world was peopled by the descendants of various portions of this race, who gradually wandered from their ancestral home in different directions.

While there is thus some reason for supposing that man overran the earth at an immensely remote period, from some rather small central region, it is utterly impossible, in the present state of knowledge, to locate this region with any degree of accuracy. The fact that the regions inhabited by the three most widely divergent types of mankind at the present time, approach each other most closely in southern and south-western Asia, is held by many to indicate that the ancestral home of man was in that region; and the fact that all of the higher animals seem to have had their earliest development in the great land mass of the northern hemisphere, may be said to favor the view that man, the highest of all organisms, was not an exception to this rule.

Classification of Mankind.—Varieties of men are usually distinguished by differences in the character of the hair, formation of the language, color of the skin, and shape of the skull. The formation of the hair, and to a lesser extent the color of the skin, seem to be more strictly hereditary than the form of the skull; and from more or less conspicuous differences in these features, all mankind may be divided into three broad classes, or *types*:

Fig. 149.—The Three Types of Mankind.

(1) the woolly-haired and brown-skinned type; (2) the straight-haired and yellowish-skinned type; and (3) the wavy-haired and whitish-skinned type.

These types differ from each other entirely in the formation of the languages used, and each type includes several groups, or *races*, which resemble each other in the more general type-characteristics, but generally differ widely in language and in minor details of feature, while each race is subdivided chiefly by minor differences of language into smaller groups, or *tribes*. The different tribes, races, and types, however, graduate insensibly into each other from long-continued cross marriages between different peoples, so that it is often impossible to draw hard and fast lines between them.

The woolly-haired type is characterized by its woolly or kinkled hair, and by the brownish color of the skin, which ranges from almost black to a light brownish tint. The peculiar character of the hair results from the fact that each hair, when duly magnified, is found to be *flat*, or tape-like. As a rule, the head in this type is very long from front to back in proportion to its width, and the jaws generally project forward, giving the profile of the face a backward slant from the mouth to the low, receding forehead. This peculiarity is stronger in some tribes than in others; it is still stronger in the monkey tribe, and is most strongly marked in the quadrupeds. The

[illegible]

[illegible]

[illegible]

tuberant, and the mental development is higher as a rule than in the woolly-haired type. One race, however—the Australian—is classed with this type on account of its straight, coarse hair; but it has the dark color, slanting face, and protruding lips of the woolly-haired type, and is considered to represent one of the lowest states, if not the lowest state, of mental development in living man.

There are five races of this type. (1) The *Australian* race is confined to the main-land of Australia. The mental and physical development of this race is very low, the bones being remarkably weak and delicate in structure. It is a significant fact that Australia, which is thus occupied by probably the least highly organized race of men, should also be strongly characterized by the lowest of the mammals—the monotremes and the marsupials. (2) The *Malay* race, though not numerous, is very widely distributed, embracing the bulk of the people in the Malay peninsula, the Malay Archipelago, and most of the islands of the Pacific and Indian oceans, from the Hawaiian Islands on the east to New Zealand and Madagascar on the west. (3) The *Mongolian* forms one of the most numerous races on the earth, embracing in its many tribes almost all the inhabitants of Asia from Okhotsk Sea to the Bay of Bengal, and westward north of the Himalaya Mountains into eastern Europe, while the Lapps and Finns of Scandinavia, the Volga Finns of central Russia, the Magyars of Hungary, and the Turks of the Balkan peninsula and Asia Minor are isolated tribes of this race. The many languages spoken by different peoples of this race may be divided into two groups, which are very remotely connected. The skin of the race is always yellowish in tone, but varies in different tribes from a dark brownish-yellow to a light greenish-yellow. The face is generally round, with prominent cheek bones, while the eye-openings are narrow, and generally slant downward toward the nose. (4) The *Esquimos* inhabit Kamchatka and the north-east extremity of Asia, the Arctic Archipelago, and a narrow strip of the Arctic American coast from Alaska peninsula to Newfoundland. The Esquimos are short, of stout build, with the round face and slanting eyes of the Mongolians, and a brownish skin, toned with yellow or yellowish-red. (5) The *Americans*, or *Red-skins*, occupy both North and South America. Many extremely different languages prevail in this wide extent of territory, yet all may be

[illegible] seems most closely [illegible] characterized by a [illegible] yellowish-yellow.

The [illegible]-haired type [illegible]

[illegible]

races. It formerly inhabited a region extending from the Bay of Bengal west to the Atlantic, embracing south-west Asia, northern Africa, and nearly the whole of Europe; but during the last 500 years, representatives of this race have spread over nearly the whole globe. This race is the most numerous on earth, and, with the Mongolian race, is the only portion of mankind possessing a written history. The hundreds of different languages and dialects of the modern descendants of the Mediterranean race may be traced to four distinct primitive languages, and upon this the classification of the race into four main branches is chiefly based; viz., (a) The *Basques*, who formerly occupied the whole of south-western Europe, but are now confined to a narrow region on the northern coast of Spain. (b) The *Caucasians*, confined to a small territory between the Black and Caspian seas about the Caucasus Mountains. (c) The *Semitic* branch, including in one group the Berbers of the Sahara west to the Atlantic, the Ethiopian, Galla, Somali, and other tribes on the north-east coast to the equator; and in another group the Jews, Syrians, ancient Chaldeans, and Arabs, a tribe of the latter forming the inhabitants of Abyssinia. (d) The *Indo-Germanic* or *Aryan* branch, which includes the ancestors of the Hindoos and Persians; the Græco-Romans, ancestors of the Greeks, Albanians, and Italians; the Celts, ancestors of the ancient Gauls, the Irish, and Welsh; the Slavonians, ancestors of the Russians and Bulgarians; and the ancient Germans, or ancestors of the modern Germans, Dutch, Scandinavians, Anglo-Saxons or Englishmen, and of a vast majority of the present inhabitants of the United States.

The present population of the world is estimated at about 1,450 millions of individuals. About 1,200 millions, nearly 83% of mankind, are included in the Mediterranean and Mongolian races, and both of these races seem to be increasing in number and in intelligence, the increase and progress of the Mediterranean race being especially rapid. The other ten principal races of mankind are estimated to include at present less than 17% of the population of the world, and these races seem to be on the whole slowly decreasing in number and approaching extinction, as a direct or indirect result of the influence of the more intelligent and civilized Mediterranean race. The estimated

number of individuals in each of the twelve principal races of mankind is given below:

Mediterranean, . .	625,000,000	Papuan, ...	2,000,000
Mongolian, . . .	575,000,000	Australian, ...	100,000
Negro, ...	130,000,000	Hottentot, ...	100,000
Dravidian, . . .	34,000,000	Esquimo, ...	100,000
Malay, ...	30,000,000	Half-breeds of the various races	11,700,000
Kaffre, ...	20,000,000		
American Indian, .	12,000,000		
Nubian,.	10,000,000	*Total,*	1,450,000,000

Man in the rudest state in which he now exists, is the most dominant creature that has ever appeared upon the earth. He forms the only highly organized species that has spread over the entire land surface of the globe. All other organisms have yielded before him. All savage men without exception seem to possess an articulate language, a knowledge of the art of making fire and of some of its uses, and the ability to make and use various rude weapons, tools, and traps with which to defend themselves and obtain food. Such inventions, by which the rudest savage achieves his pre-eminence among organisms, are the direct results of the development of his powers of observation, memory, curiosity, imagination, and reason.

The reasons why certain tribes, and not others, have risen in the scale of civilization from this rude state can not be fully given. Progress seems to depend upon combinations of favorable conditions far too complex to be followed out. The remarkable fact, however, has frequently been observed that all high civilization has developed in the north temperate zone, and that the native races of this zone, when first visited by civilized men, had arrived at a higher state of civilization than the native tribes of the torrid and frigid zones. It would seem, therefore, that an extensive land area, combined with a

temperate climate, is a physical condition favorable to the development of intelligence and civilization.

Reflection suggests a possible explanation for this. Development is the result of mental activity, and hence would generally be greatest in a region that afforded the greatest *incentive* to mental action. An extensive region possesses a greater variety of environments than a contracted region, and hence would develop a greater number of different tribes of men. The natural competition of these tribes for mastery, would form a constant incentive to greater mental activity in the larger region. In extensive *temperate* regions, an additional incentive to mental action is afforded by the effect of the climate upon vegetable and animal life, and hence upon man's food supply. The regular alternation in such regions of a long, warm summer, when food is plenty, with a long, cold winter, when food is very scarce, is in marked contrast to the constant summer of the torrid zone, which affords a perpetual abundance of food in the moist regions, but causes a perpetual dearth of food in the dry, desert regions; while in the frigid zones there is a perpetual dearth of food because of the long, cold winters. Hence, the climate of the temperate zones is peculiar in affording a constant incentive to collect and cure a store of food during the summer upon which to draw during the following winter. The gradual development of foresight and ingenuity involved in such a collection and preservation of food for future use, would of itself raise a tribe in the scale of civilization, and such mental development would lead to further progress in other directions.

Domestic Plants and Animals.—The great mass of mankind to-day—all, indeed, but the rudest tribes—depend chiefly for food and clothing upon *domestic plants and animals*. These form the portion of the organic world which man has subjugated. It is a remarkably small portion when compared with the world's flora and fauna. Among more than a million species of plants and animals, the cultivated plants form only about 300 species, and the domestic animals only about 200 species. By far the most important of these plants and animals were reduced to a domestic state *in prehistoric times, and can not now be*

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[illegible]

Metals.—Among the inorganic substances whose use by man indicates his progress in civilization, are the metals. Few of these occur in a pure state in nature. Most of them are found as stony substances, or *ores*, in which the metal occurs only as a chemical ingredient, and from which it is obtained only by more or less intricate artificial processes. Some metals are found in the metallic state, but almost always *alloyed*, or mixed, with other metals, and their separation is generally difficult. But even after the pure metal is obtained, more or less difficult artificial processes are required to apply it to the various purposes of man. It is chiefly through an increasing knowledge of the laws of nature, by which the metals and other inorganic substances can be more easily obtained and applied, that modern civilization is advancing.

The eight metals in most common use to-day—iron, copper, tin, zinc, lead, gold, silver, and mercury—seem to have been known in the earliest historic time; but as geographical knowledge increased, the sources from which they could be obtained became more numerous, while, with the increase of physical knowledge, easier and cheaper methods for reducing them were discovered, and the ways in which they could be rendered beneficial to man multiplied prodigiously. Not a day passes in which every individual of all civilized races does not repeatedly derive benefit, either directly or indirectly, from the use of most or all of these metals, and the amount and variety of their use by any people is an infallible index of their degree of civilization.

Distribution.—Most of the metals or their ores are widely distributed over the globe, occurring among rocks of various geological ages. They are generally most abundant in regions of highly tilted, disturbed, or metamorphosed strata, such as characterize mountain regions. This is partly due to the fact that the enormous erosion in such regions has exposed a greater variety of formations; but it seems probable that many of the metals were

[illegible]

[illegible] England. [illegible]

from Almaden, Spain. *Antimony*, *platinum*, and *nickel* are the only metals of comparatively recent discovery that have been largely used in the arts. The ore of antimony is obtained chiefly in the East Indies, but is found in both Europe and North America. Platinum, like gold, is found in minute metallic grains in alluvial deposits. Three fourths of the world's supply comes from the Ural Mountains. Nickel ore in minute quantities is very widely distributed. The mines of the Sudbury district in Canada, furnish the world's chief supply. It is also found in Saxony, Sweden, and New Caledonia.

Various other minerals besides the metals are largely collected and used by man. Among these are the many kinds of building stone, clays for making brick and pottery, marls for fertilizing the soil, salt, and the precious stones or gems, used both in the arts and for ornaments. But the mineral whose use is confined most exclusively to *civilized* man, and the loss of which would affect him most seriously, is *coal*, or mineral fuel.

Coal is the most widely distributed and the cheapest source of great and easily available heat, or kinetic energy, that man has ever discovered. It is only since the recognition of its great thermal value, about 700 years ago, that iron and steel have been manufactured cheaply and in large quantities, while the rapid development of all kinds of manufacturing, which followed the invention of the steam engine 150 years ago, was largely due to the relative abundance and cheapness of mineral fuel.

Formation of Coal.—True coal, though a stony substance occurring in layers interstratified with sedimentary rocks of various geological eras, is organic matter. It is chiefly the metamorphosed remains of a *swamp vegetation* which flourished on the earth's surface thousands of years ago. As such vegetation died and fell, it was covered with water, and thus protected from the atmosphere, and consequently from rapid decomposition into stable compounds—carbonic acid, etc. Thus, a thick layer of or-

[illegible] bottom of the swamp. [illegible] vegetable sediment [illegible]. When subsequent eleva- [illegible] sediment, brought the surface [illegible] again. Warm [illegible] sediment [illegible] above increased. The [illegible] gradually became con- [illegible] temperature [illegible] they became [illegible] the complex and [illegible] carbon. [illegible] compounds [illegible] which [illegible] water, [illegible]. The residue [illegible] carbon, [illegible] hydrogen. [illegible] petroleum.

[illegible] the period when [illegible] developed [illegible] stage [illegible] stems [illegible] consequent ages, [illegible] which becomes [illegible] carbonized

as we proceed, until, in the Jurassic period, true bituminous coal occurs. In regions that have been subjected to exceptionally great heat or pressure the process has been hastened, and in some regions has progressed beyond the stage of bituminous coal; thus, where the carboniferous strata in north-eastern Pennsylvania are most extremely plicated and contorted, the inclosed seams of coal have lost much of their bitumen, and have been compressed into the hard, more thoroughly carbonized, and most valuable heating coal—*anthracite*. In the older contorted rocks of Rhode Island and Massachusetts, anthracite coal has advanced a stage further and lost much of its value as fuel, by transformation into nearly pure carbon or *graphite*. In several localities in the West, where lava dikes have intersected the relatively young cretaceous and tertiary strata, the included seams of *lignite* are found to have been transformed, in the vicinity of the dikes, into true bituminous coal, or even anthracite, by the great heat of the lava.

Distribution.—Deposits of coal, near enough to the earth's surface to be accessible, are widely distributed. Fully one tenth of the area of the United States, and about the same proportion of Europe, are known to be underlaid by workable coal, while deposits of great but unknown extent exist in China, Canada, Australia, India, Chile, Brazil, and elsewhere.

In the eastern part of the United States, coal of carboniferous age is found, under: (1) the whole Appalachian plateau from northern Pennsylvania to central Alabama—about 64,000 square miles; (2) the central part of southern Michigan—about 7,000 square miles; (3) the southern two thirds of Illinois, south-western Indiana, and western Kentucky—about 47,000 square miles; and (4) from central Iowa southward across western Missouri and Arkansas and eastern Nebraska, Kansas, and Oklahoma into central Texas—about 99,000 square miles. The first of these coal-fields is by far the most extensively worked, and supplies more than three fourths of the yield of the United States, while practically all of our anthracite coal comes from the small area of this field in Pennsylvania. True bituminous coal of triassic age is found in central Virginia and North Carolina. In the western half of the United States the surface is largely composed of rocks more recent than the Jurassic, and the extensive coal deposits found in nearly all the states have, in

general, advanced only to the stage of lignite. This, though valuable as fuel, and closely resembling coal, is not so valuable for some manufacturing purposes. In the vicinity of dikes in this region, as before mentioned, and in the regions of contorted strata along the flanks of mountain ranges, where the great erosion has exposed older rocks, true bituminous and anthracite coal are found. Over 500 million tons of coal are used annually in the world. About one third of this is mined in the United States; over one half of the remainder in England; and most of the rest in continental Europe—Germany being by far the largest producer.

Conclusion.—Thus, through their continued *use, or exercise*, man's mental powers have gradually increased. With his constantly expanding faculties, his observation of nature becomes more exact, and he daily recognizes more clearly the dependence of her manifold phenomena upon each other. In numerous instances he has gained a sufficiently clear comprehension of her great and immutable laws to invoke their aid at will in securing results beneficial to himself. By incessant *exertion*, he maintains his limited power to thus direct the operation of these laws into such channels that they may produce about him the peculiar and artificial environment essential to civilization. But the observation of nature involved in the attainment of high civilization, results in far more than the development of man's inventive genius and the improvement of his material surroundings. In partially revealing the harmonious, yet marvelously intricate plan on which the world has been modeled, it teaches him of the utter insignificance of his own unaided powers, and increases his faith in and reverence for the Divine Wisdom which devised and which maintains it all.

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